

**FINAL REPORT—REMOTE MINE SITE  
DEMONSTRATION PROJECT**

**MINE WASTE TECHNOLOGY PROGRAM  
ACTIVITY III, PROJECT 1**

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**Prepared for:**

U.S. Environmental Protection Agency  
Office of Research and Development  
National Risk Management Research Laboratory  
Cincinnati, Ohio 45268  
IAG ID No. DW89935117-01-0

and

U.S. Department of Energy  
Federal Energy Technology Center  
Pittsburgh, Pennsylvania 15236  
Contract No. DE-AC22-96EW96405

March 1998

**REVIEWS AND APPROVALS:**

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Approved by: \_\_\_\_\_



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March 1998

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## **Executive Summary**

This document is the final report for the Mine Waste Technology Program (MWTP) Activity III Project 1—Remote Mine Site Demonstration Project. The demonstration was performed at pilot-scale at the Crystal Mine, which is located 7 miles north of Basin, Montana.

The MWTP is funded by the U.S. Environmental Protection Agency (EPA) and is jointly administered by the EPA and the U.S. Department of Energy (DOE) through an Interagency Agreement.

MSE Technology Applications, Inc. (MSE), of Butte, Montana, is a prime contractor of DOE and is responsible for operating the Western Environmental Technology Office facility. MSE responsibilities for the Remote Mine Site Demonstration Project were site selection, technology selection, technology train design and installation, development of regulatory plans and programs, demonstration monitoring, maintenance, and first line quality assurance (QA). Both the EPA and the DOE provided program administration, demonstration oversight, technical review, and QA/audit control.

The purpose of this demonstration was to evaluate the performance of a pilot-scale technology for the remediation of acid mine drainage specifically without operator assistance in a self-regulating manner. The technology selected for the demonstration was the AQUA-FIX system, which has a limited application at the Crystal Mine site relative to the project-imposed condition of minimal operator assistance.

The concentration of lead being discharged by the system met the boundary conditions 99% of the time. However, the concentration of lead within the Crystal Mine drainage is extremely low and was lower than the boundary conditions for large periods during the demonstration.

The concentration of zinc being discharged by the system met the boundary conditions only 44% of the time. This was largely because the pH of the treated water must reach a value near 10 to successfully remove zinc to the level of the boundary conditions.

The concentrations of aluminum, iron, and copper being discharged by the system met the boundary conditions 64%, 57%, and 52% of the time. This was largely because these three elements require the pH of the treated water to reach a value near 7 to successfully reach the level of the boundary conditions.

During the first year of operation, the system performed as designed only 36% of the time (131 days). Conversely, during the first year of operation, the process failed to perform as designed 64% of the time (234 days). The majority of the time (184 days or 79%) that the system did not operate as designed, the failure was due to a lack of knowledge by the operational staff assigned to the demonstration. The remaining days the system did not operate as designed (60 days or 21%), the failures were largely due to plugging of the alkaline reagent within the throat of the AQUA-FIX. This problem continued to plague the project until the problem was properly diagnosed in December of 1995.

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During the second year of operation, the system performed as designed 70% of the time (209 days). Conversely, during the second year of operation, the process failed to perform as designed 30% of the time (91 days). Lack of knowledge by the operational team accounted for 37 of the 91 failed days or 41% of the failures.

During the second year of operation, the lower portal of the Crystal Mine collapsed twice. These events resulted in the process train being clogged with debris and/or being bypassed by the acidic water. This clogging of the system and intermittent flow of water resulted in the failure of the system for a total of 35 days or 38% of the downtime during the second year of operation.

The remaining days that the system did not operate as designed (19 days or 21%) during the second year was largely due to plugging of the alkaline reagent within the throat of the AQUA-FIX.

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## 1. Introduction

This document is the final report for the Mine Waste Technology Program (MWTP), Activity III, Project 1, aqueous point-source discharge at a remote mining site. The project was funded by the U.S. Environmental Protection Agency (EPA) and jointly administered by the EPA and the U.S. Department of Energy (DOE) through an Interagency Agreement (IAG). The report will detail the project preparation, technology selection process, demonstration site, field testing, and results. A field demonstration of this innovative technology was intended to illustrate the viability and feasibility of using the technology contained in the process train to remove contaminant species from an aqueous point discharge for a period up to 2 years with minimal operator assistance.

### 1.1 History

The specific technical issue to be addressed by the project was Mobile Toxic Constituents— Water and the specific waste form, aqueous point-source discharge emanating from a mine portal at a remote, idle mine site that requires infrastructure and power sources.

### 1.2 Project Purpose

The purpose of this project was to develop technical information on the ability of a technology process train to treat acidic mine drainage at a remote mine waste site with minimal operator assistance. Weather conditions, variable flow rates, and compositions of the drainage were taken into consideration. For this demonstration, treatment of the acidic drainage consisted of removing toxic dissolved metallic and nonmetallic constituents from the water and increasing the pH of that water such that the effluent from the technology process train was near neutral.

### 1.3 Project Schedule and Milestones

Formal start of the project was planned for February 1, 1993. Preliminary work was completed before that date. Major project milestones were the reports at the completion of each project phase and are shown in Table 1-1. The summary schedule for the project is shown in Figure 1-1.

### 1.4 Success Criteria

The Remote Mine Site Demonstration Project is a technology demonstration project not a mine waste site remediation project. Therefore, the project did not attempt to develop or undertake a remediation scheme for the Crystal Mine site. The project developed technical information on the ability of a technology process train to treat acidic, metal-laden mine drainage at that remote mine waste site. This data included process and environmental information, the effects of weather on the operational conditions of the system, the choice of a reagent fed to the system, and operational methods applied to the system at the site. Data gathered was not limited to the effectiveness of the system in removing contaminants from the acidic mine drainage, it also focused on the feasibility and appropriateness of using the technology process train at such a site and under such conditions. Beyond this data, the project determined the applicability of different unit processes of the treatment train to the problem. Boundary conditions for the contaminants discharges were determined and are shown in Table 1-2.

Table 1-1. Major project milestones.

Milestone	Date
Conceptual Design Report	May 15, 1993
Preliminary Design Report	July 15, 1993
Test and Evaluation Plan	July 15, 1993
Health and Safety Plan	June 1, 1993
Laboratory Research and Testing Report	August 1, 1993
Receipt of Discharge Permit	October 1, 1993
Receipt of Waste Disposal Plan from State	October 1, 1993
Definitive Design Report	October 15, 1993
Completion of NEPA Requirements	January 15, 1994
Field Construction Contract Finalized	March 15, 1994
Final Project-Specific QAPP	April 15, 1994
Field Construction Completed	July 1, 1994
Initiate Field Demonstration	August 15, 1994
Complete Field Demonstration	July 1, 1996
Final Project Report	June 15, 1997

Table 1-2. Discharge boundary conditions in mg/L.

	Cu	Zn	Pb	Cd	As	Fe	Al	Mn	SO <sub>4</sub>	pH	TSS
Boundary Condition	0.3	1.5	0.6	0.1	1.0	1.0	2.0	1.0	500	6.0-9.0	30



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## 2. Demonstration Site Description

The field activities of the Remote Mine Site Demonstration Project were conducted by MSE personnel outside the lower adit of the Crystal Mine. The Crystal Mine is located approximately 7 miles north of Basin, Montana, at an elevation of 7,500 feet. A general map and a site map are shown in Figures 2-1 and 2-2 respectively.

### 2.1 Crystal Mine Workings

The Crystal Mine workings consist of two horizontal levels that are no longer open to the surface and a sublevel between the two major levels. Trench-like workings have been developed along the surface exposing the mineralized zone. The upper subsurface tunnel was the first working of the mine developed, followed by the lower sublevel. The surface trench was the last to be opened. The subsurface workings are approximately 5,100 feet in length.

### 2.2 Site Characteristics

The mine site is a remote, abandoned acid-producing mine that encompasses 22 acres of land and poses a threat to the environment and human health. Drainage parameters that characterize the mine are:

- a constant stream temperature of 33E-35 EF;
- a pH of approximately 2-3;
- dissolved heavy metals consisting primarily of iron (Fe), zinc (Zn), copper (Cu), aluminum (Al), lead (Pb), and cadmium (Cd) with Fe concentrations varying between approximately 350 parts per million (ppm) in the spring to approximately 50 ppm in the winter.

The acid mine drainage from the lower workings of the Crystal Mine flows at a rate of less than 20 gallons per minute (gpm) for most of the year. Flow increases to as much as 100 gpm during the spring snowmelt (May-June) and results in surface and groundwater contamination. Acid mine water discharges into Uncle Sam Creek that travels along a 7-mile stretch where it discharges into Cataract Creek; no aquatic life is present along this stretch. During drought seasons, the flow rate of Cataract Creek reduces to a minimum, becoming vulnerable to the dissolved metals being carried by Uncle Sam Creek. This increase in toxic metal concentration causes aquatic damage to Cataract Creek. Figures 2-3 through 2-7 show the Crystal Mine site adit, the flow of acidic drainage, the loading trestle and pond, the original drainage pond, Uncle Sam Creek, and downstream Uncle Sam Creek with damage from heavy metals.

During base flow conditions, the water emanating from the lower workings of the Crystal Mine contains approximate concentrations of dissolved metals: 60 milligrams per liter (mg/L) of Zn, 50 mg/L of Fe, 15 mg/L of manganese (Mn), 12 mg/L of Al, 13 mg/L of Cu, 0.6 mg/L of arsenic (As), and 0.8 mg/L of Cd. During peak flow conditions, these concentrations increase to the following approximate concentrations of dissolved metals: 90 mg/L of Zn, 350 mg/L of Fe, 15 mg/L of Mn, 43 mg/L of Al, 94 mg/L of Cu, 63 mg/L of As, and 1 mg/L of Cd.

The variance in pH between base and peak flow conditions is less than 0.5 pH units. The lower pH occurs during the peak flow conditions.







Figure 2-3. Adit with acidic drainage.



Figure 2-4. Pond and loading trestle.



Figure 2-5. Original acidic drainage pond at Crystal Mine site.



Figure 2-6. Uncle Sam Creek receiving acid drainage.



Figure 2-7. Uncle Sam Creek downstream from the Crystal Mine with damage from heavy metals.

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### 3. Predemonstration Activities

Several preliminary activities were required by MSE before the demonstration could be conducted. These activities included technology selection, site selection, regulatory documents, and analysis laboratory.

#### 3.1 Technology Selection

Two technology process trains (the AQUA-FIX system and the Inline Aeration system) were recommended for demonstration in Activity I, Appendix A. Information concerning each system as applied to the Crystal Mine site was limited. MSE personnel traveled to the sites where these technologies were being applied to acid mine drainage at active mines in the coal fields of the eastern United States. The data generated during this trip led to the selection of the AQUA-FIX system as the superior technology for the field demonstration.

#### 3.2 Site Selection

The site was selected based on a number of criteria, which included weather conditions, variable flow rates, compositions of the drainage, quantity of characterization data, and location. The recommended site was the drainage emanating from the lower Crystal Mine portal into Uncle Sam Gulch.

Selection of the correct sampling sites was necessary to ensure the project objectives were met. The sampling sites had to meet the following criteria:

- external contamination had to be minimal;
- location had to be representative of the entire wastestream;
- the treatment train being monitored had to be as close as possible to the treatment process to prevent chemical changes in the wastestream;

- raw water samples had to be taken as close as possible to the lower adit of the Crystal Mine to prevent chemical change in the wastestream; and
- sampling sites were chosen so the effect of each component in the treatment train could be analyzed.

The sampling locations for the treatment train are shown in Figure 3-1 as squared box numbers. Location of the sampling points met the above criteria. Downstream water sampling sites (Figure 3-2) were used to distinguish the effect of the mine drainage on the environment.

#### 3.3 Quality Assurance Project Plan

A QAPP was developed for the project and was submitted to the EPA's Office of Research and Development for review and approval. The QAPP was prepared against the standards provided in *Preparation Aids for the Development of QA Project Plans*, (EPA/600/8-91/003 through 006). Additionally, it served as a Standard Operating Procedure for the sampling team, the sample preparation team, the analytical team, and the data reduction team. The QAPP document was approved.

#### 3.4 Health and Safety Plan

A health and safety plan specific to the project was developed to establish the procedures and requirements used to reduce health and safety risks to persons working at a demonstration site. Personnel training, medical surveillance, site work practices, hazard evaluation, personal protection equipment, decontamination, and emergency response were all part of a detailed plan of responsibilities. In addition to the health and safety plan, activities were according to applicable regulations of the Mine Safety and Health Administration, the Occupational Safety and

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Health Administration (OSHA), and the MSE Risk Management Manual.

### **3.5 Permitting**

The State of Montana has adopted the federal regulations that determine effluent concentrations from point-source discharges as a portion of regulations controlling the Montana Pollution Discharge Elimination System (MPDES). A number of water pollution regulations were applicable and relevant to this demonstration; these are listed in Table 3-1. In addition to these values, the State of Montana has a nondegradation statute that applies to any activity of man that would cause a new or increased source of pollution to State waters.

It was determined that the sludge introduced back into the old mine workings was nontoxic. Therefore, it was excluded from any permit requirements by the Department of Environmental Quality of the State of Montana.

MPDES Discharge Permit #MT-002998 was issued with the stipulation that the effluent coming out of the portal contained higher concentrations of the elements listed than the effluent from the treatment train. The pH required was within 6.0-8.5.

A special use permit from the Forest Service was required to use a portion of this property. This permit (#2720) was granted.

Conservation District permit #310 was required by Jefferson County before any work near the stream bed could be done. This requirement falls under the Stream Bed Preservation Clean Water Act #N-08-94.

Table 3-1. Regulatory values for contaminants in water in mg/L.

	Ore Mining and Dressing Point-Source Category		National Primary Drinking Water Regulations		Montana Inorganic Chemical MCLs		Water Quality Criteria Fresh Water (Gold Book)		National Secondary Drinking Water Regulations
	1 day Max.	30 day Ave.	MCL	MCLG	MCL		ACUTE	CHRONI C	SMCL
Cu	0.300	0.150		1.300			0.018 +	0.012 +	1.000
Zn	1.500	0.750					0.120 +	0.110 +	5.000
Pb	0.600	0.300	0.050	0.000	0.050		0.082 +	0.0032 +	
Hg	0.002	0.001	0.002	0.002	0.002		0.002	0.000012	
Cd	0.100	0.050	0.010	0.005	0.010		0.0039 +	0.0011 +	
As <sup>+3</sup>	1.000	0.500	0.050		0.050		0.360	0.190	
TSS	30.00	20.00							
pH	6.0 - 9.0	6.0 - 9.0						6.5 - 9.0	6.5 - 8.5
Ba			1.000	2.000	1.000				
NO <sub>3</sub>			10.00	10.00	10.0 0	20.00 *			
NO <sub>2</sub>				1.000					
Se			0.010	0.050	0.010		0.260	0.035	
Ag			0.050		0.050		0.0041 +	0.00012 +	0.100
Cr <sup>+3</sup>			0.050	0.100	0.050		1.700 +	0.210 +	
F			4.000	4.000	4.000				2.000
Cl							0.019	0.011	250.0
Al									0.05 - 2.0
Fe								1.000	0.300
Mn									0.050
SO <sub>4</sub>			500 **						250.0
TDS									500.0



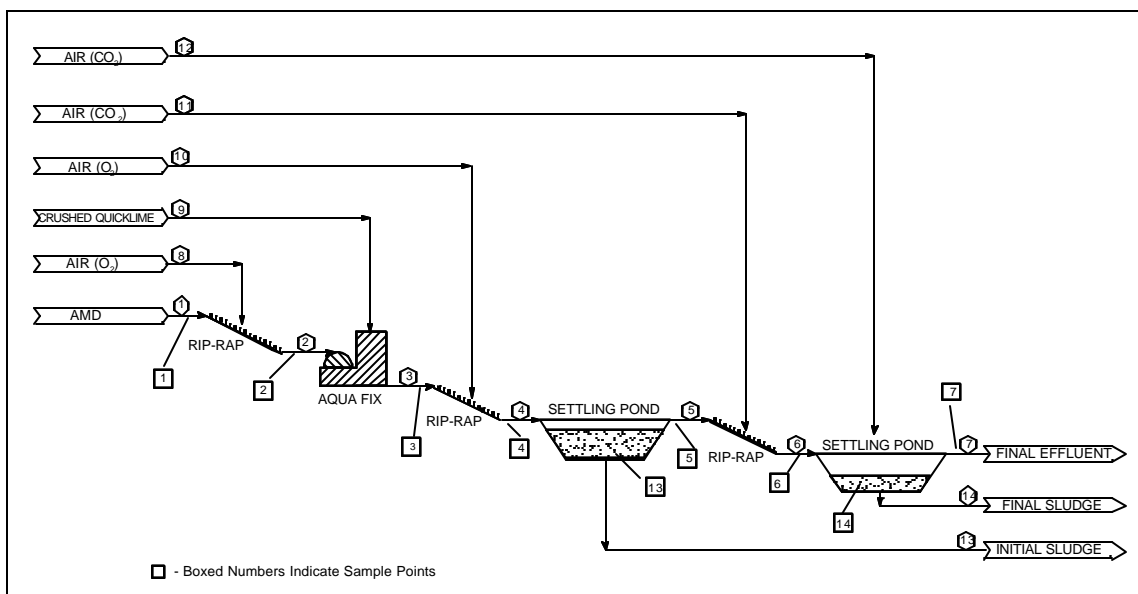


Figure 3-1. Process flow of water sampling sites.

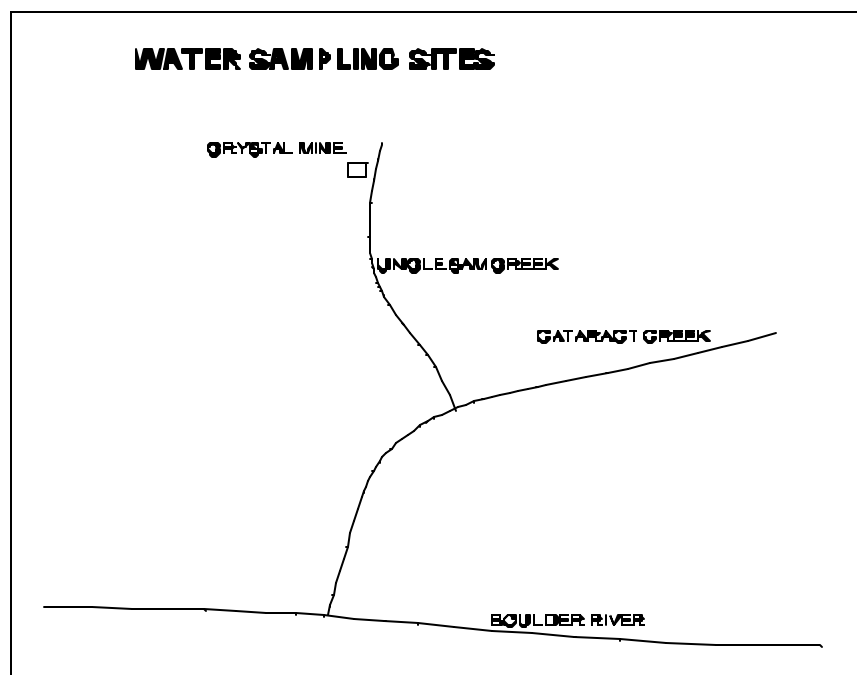


Figure 3-2. Water sampling sites.

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## 4. Demonstration Technology Description

A treatment technology train was constructed at the mouth of the lower portal of the Crystal Mine and consisted of six unit operations, which are described below. The laboratory design data and graphs for these operations are shown in Figures 4-1 through 4-7.

and was directly discharged into Uncle Sam

### 4.1 Initial Oxidation

This unit operation consisted of a 110-foot length of corrugated polyvinyl chloride (PVC) pipe that was 12 inches in diameter. The turbulent flow of water through the pipe caused air to be entrained into the water. The oxygen in the air then dissolved into the water and partially oxidized the dissolved ferrous iron in the water to ferric iron. The percentages of ferric and ferrous iron dissolved in the water discharging from the lower portal of the Crystal Mine were 85% and 15% respectively. As such, the oxidation required from this operation was minimal. The small amount of oxidation that was required precluded much examination of oxidation methods. However, the oxidation of ferrous iron to ferric iron is slow at low pH. As such, oxidation prior to raising the pH is not recommended. The entrainment of as much dissolved and suspended oxygen into the water prior to raising the pH increases the overall speed of oxidation. A residence time of approximately 30 seconds was used for this unit.

The second purpose of this unit was to direct the aqueous discharge to the alkaline reagent addition unit. Two weir boxes are within this flow to separate the aqueous discharge into three streams. Stream one flowed under the AQUA-FIX wheel while stream two flowed over the AQUA-FIX wheel and supplied power to the wheel. These streams were split to control the amount of reagent added to the water. Stream three bypassed the process train

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Creek when necessary. Figures 4-8 and 4-9 are schematics of the two weir boxes. Figure 4-10 shows the Crystal Mine portal, and Figure 4-11 shows the AQUA-FIX building at the site with the weir boxes located to the right.

The weir box with the adjustable gate (Figure 4-9) was meant to self regulate the flow of water over the AQUA-FIX wheel relative to variances in flow from the mine portal. However, the contained volume of the weir was too large and tended to buffer the changes; consequently, the system required regulation by hand.

#### **4.2 Alkaline Reagent Addition**

This unit operation consisted of a feeder that was powered by water (AQUA-FIX system), which directed an alkaline reagent, pebble quicklime (CaO), into the acidic water. The resultant reaction of the pebble quicklime with the acidic water raised the pH of the water. Residence time of the aqueous discharge in the unit was a few seconds and did not lead to any sizable reaction. The AQUA-FIX system was housed within a small building (12 feet by 12 feet). The flow channel through this building consisted of PVC piping of various sizes.

The channel into which the AQUA-FIX discharged the quicklime reagent was specifically designed to collect reagent and increase the velocity of the acidic drainage to carry the nonreacted reagent out of the AQUA-FIX building and into the next stage of the facility. This trough was constructed of PVC pipe and sheeting. Figure 4-12 shows the AQUA-FIX system.

The lime storage hopper provided quicklime to the smaller hopper mounted on the AQUA-FIX feeder. The storage hopper is a 3,000-gallon cone-bottom tank located immediately adjacent to the AQUA-FIX building. This tank can accommodate approximately 11 tons of reagent,

which was more than adequate for a year of operation. The design use of the reagent was to vary seasonally as shown in Table 4-1.

No conversion of CaO to CaCO<sub>3</sub> was observed during the operation. System operation used approximately 10% more reagent than the stoichiometry of the reactions that occurred. This was designed for and was due to lime buildup and nonreaction within the ponds.

#### **4.3 Final Oxidation**

This unit operation also consisted of corrugated PVC pipe that was 12 inches in diameter. The turbulent flow of water through this section of the channel caused air to be entrained into the water. The oxygen in the air dissolved into the water partially oxidizing the dissolved ferrous iron to ferric iron. The length of this pipe was approximately 120 feet, which yielded a residence time of less than 1 minute. This residence time was not sufficient to oxidize all the iron in the water to the ferric state. However, the length of this pipe was controlled by the available space at the project site.

Figure 4-13 shows the AQUA-FIX building, the hopper, and the pipe carrying flow to the ponds.

#### **4.4 Initial Solid-Liquid Separation**

This unit operation consisted of two ponds lined with high-density polyethylene (HDPE), which was 40 mils thick. The dissolved metallic components in the acid mine drainage formed solid metallic hydroxide compounds on the addition of alkaline reagent and air. These solids precipitated from solution to form a metallic hydroxide sludge. The settling time for the concentrated hydroxide sludge in these ponds was 57 minutes. The quantity of sludge produced over 1 year of operation was 368,000 gallons or 50,000 cubic feet. Therefore, the design volume of each pond was 25,000

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cubic feet per pond with a surface area of 3,600 square feet. The ponds retained all of the sludge and allowed 2 feet of freeboard for excess capacity. The residence time within these holding ponds was approximately 5 days longer than that required to allow for settling. This residence time in the ponds allowed the ferrous iron in the sludge to be oxidized to ferric iron and for reaction of the metals with the alkaline reagent to go to near equilibrium. Periodically throughout the project, the sludge in the ponds was removed and disposed in a safe and environmentally acceptable manner by putting it into the sealed subsurface workings of the mine.

The settling ponds with the baffle system installed operated efficiently. The total suspended solids leaving these ponds was less than 10 ppm for 90+% of the operation of the system. The entry point for the treated water into the ponds was at the bottom of each pond. This tended to eliminate problems of the water in the pond freezing and not allowing the water to enter each pond. In addition, this entry point tended to cause the creation of a mound of sludge above the entry point. This mound acted much like a second filter and reaction media for water entering the ponds.

The sludge buildup in the ponds was disposed in the subsurface workings of the Crystal Mine by pumping the sludge into an airshaft of the mine. No other economically viable options were available for this material. Disposal on the surface is not an option, and hauling to the nearest available landfill would have meant a haul distance of nearly 50 miles. The operators of the nearest landfill would not accept the sludge without it being filter pressed to a dryness of 70% moisture, which would be very costly.

hold a sufficient quantity of water to create a 2-day residence time for the solution that allowed late-forming solids to precipitate and a sufficient

#### **4.5 pH Adjustment**

This unit consisted of corrugated PVC pipe that was 12 inches in diameter. The turbulent flow of water through this apparatus caused air to be entrained in the water. The carbon dioxide in the air then dissolved into the water and reacted with the excess hydroxide produced by the alkaline reagent reducing the pH of the solution. To lower the pH of the effluent solution to a value of 8, a residence time of greater than 5 hours was required (See Figure 4-10) Because of the limited amount of space at the demonstration site, the residence time in the piping was less than 2 minutes. Therefore, a portion of the required residence time was made up in the final pond. Figure 4-14 shows the ponds at the Crystal Mine site. The design for ponds 1 and 2 are shown in Figure 4-15.

#### **4.6 Final Solid-Liquid Separation**

This unit operation consisted of a single pond lined with 40-mil HDPE. The pond served to

amount of carbon dioxide to react with the water. This was intended to reduce the pH to a value between 6.5 and 8. The single pond that

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comprises this unit was designed to contain more than 100,000 gallons of storage capacity. This volume yielded a residence time of more than 60 hours for a flow of 20 gpm.

The above values were design values. The pond that was constructed contained approximately 20,000 gallons. This smaller pond was required due to restrictions on land use by the U.S. Forest Service. Therefore, the final pond did not allow enough residence time under most flow rates. The final pond is shown in Figure 4-16. The pond capacity of the final pond allowed for emergency hydroxide storage; however, this storage was never required.

Table 4-1. Reagent use and sludge production over a year.

Sample Date	Flow (gpm)	Duration (days)	Reagent Used (lb)	Sludge Produced (gal)
4/16	29.5	77	2,033	41,358
5/18	25.2	32	2,835	52,618
6/8	45.2	22	2,334	43,402
7/1	51.0	34	4,088	76,378
8/15	33.0	37	1,836	35,640
9/1	26.8	34	1,738	34,615
10/22	30.8	46	1,811	36,035
12/15	29.3	83	2,370	48,167
ANNUAL TOTALS	16,979,18	365	19,045	368,213

Reagent feed rate vs. rpm. (Graph A)

RPM	Feed Rate (grams per minute)
1.3	44.3
2.4	78.6
3.7	127.3
5.1	173.4
6.5	216.8
8.1	279.5
10.4	346.3
15.2	526.7

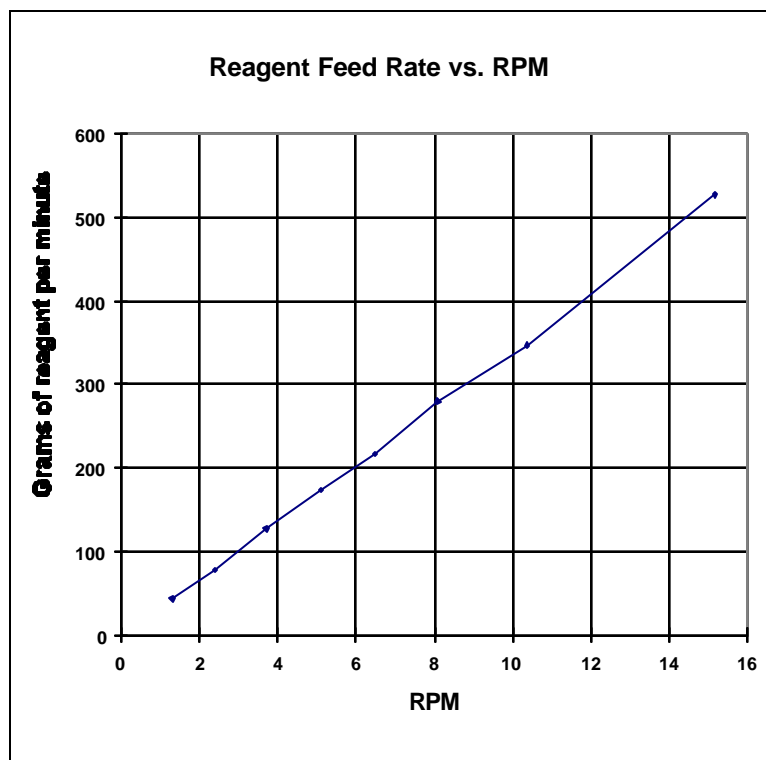


Figure 4-1. Graph A.

Water flow rate vs. rpm. (Graph B)

RPM	Water Flow Rate (gpm)
6	0.7
10.5	1.15
17.5	2.28

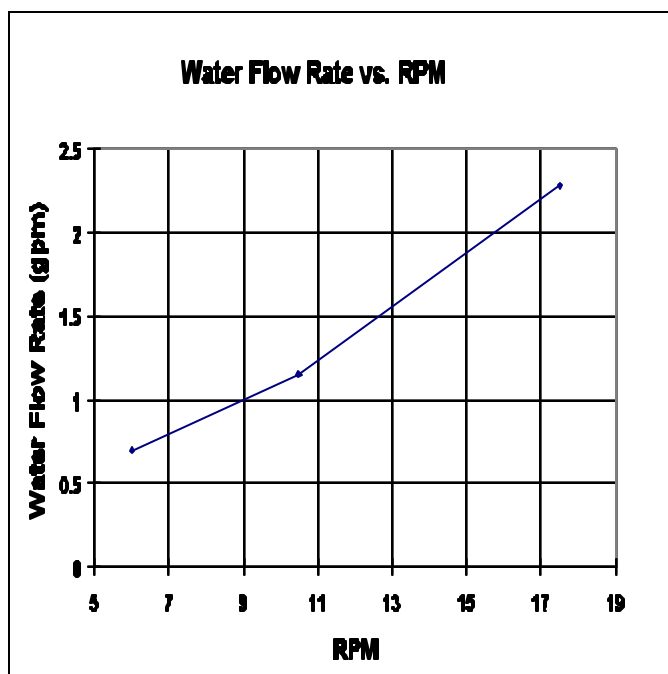


Figure 4-2. Graph B.

% Oxidation vs. pH. (Graph C)

pH	% Ferrous Oxidized		
	30 sec.	45 sec.	60 sec.
6	4	7	9
7	6	8	11
8	9	11	14

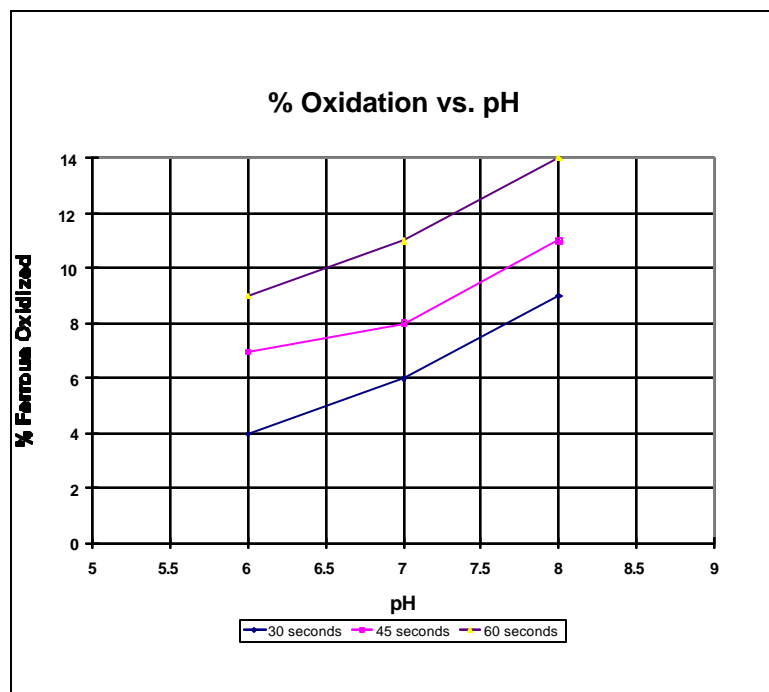


Figure 4-3. Graph C.

Sludge height vs. time. (Graph D)

Sludge Height vs. Time	
Height (cm)	Time (min)
29	0
28	2.03
27	5.25
26	8.42
25	11.13
24	13.47
23	16.15
22	19.42
21	24.12
20	30.28
19	39.63
18	54.67
17.5	70

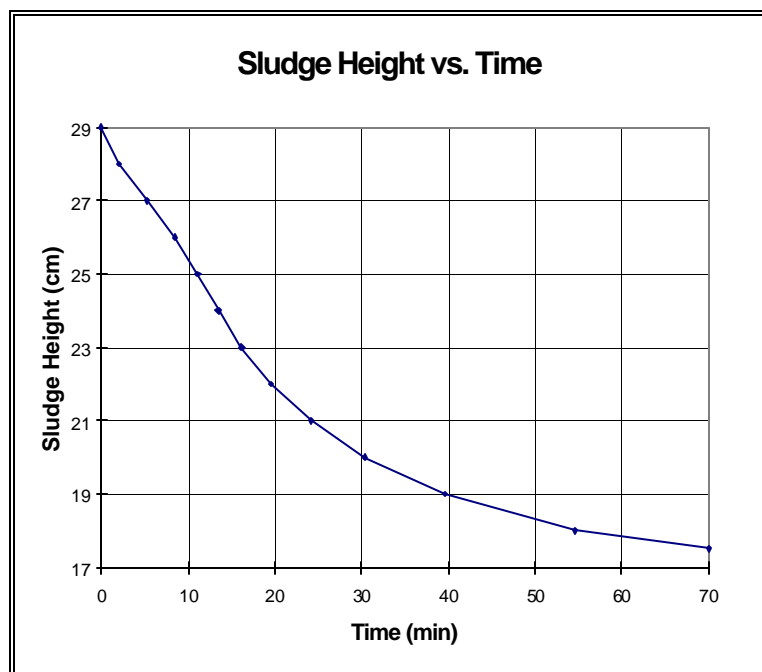


Figure 4-4. Graph D.

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Sludge height vs. time. (Graph E)

Sludge Height vs. Time	
Height (cm)	Time (min)
34.2	0
31	1.31
30	2.07
29	2.37
28	2.56
27	3.22
26	3.41
25	3.59
24	4.21
23	4.39
22	4.57
21	5.16
20	5.33
19	5.50
18	6.06
14	7.16
13	7.33
12	7.57
11	8.11
10	8.28
9	8.42
8	8.58

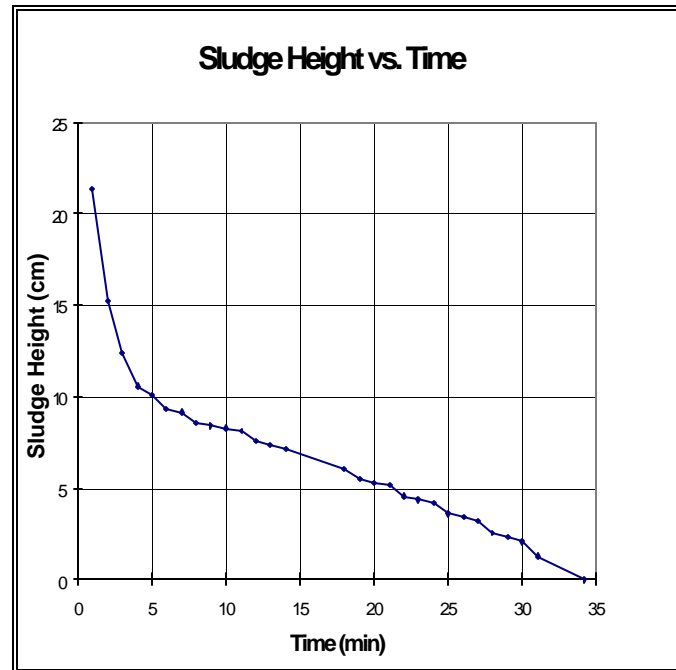


Figure 4-5. Graph E.

% Oxidation vs. time. (Graph F)

% Oxidation vs. Time			
% Oxidized	pH		
	8	9	10
85	47.3	14.1	4.8
90	60.9	29.6	10.1
95	68.5	38.7	19.2
97	72	41.4	23.1

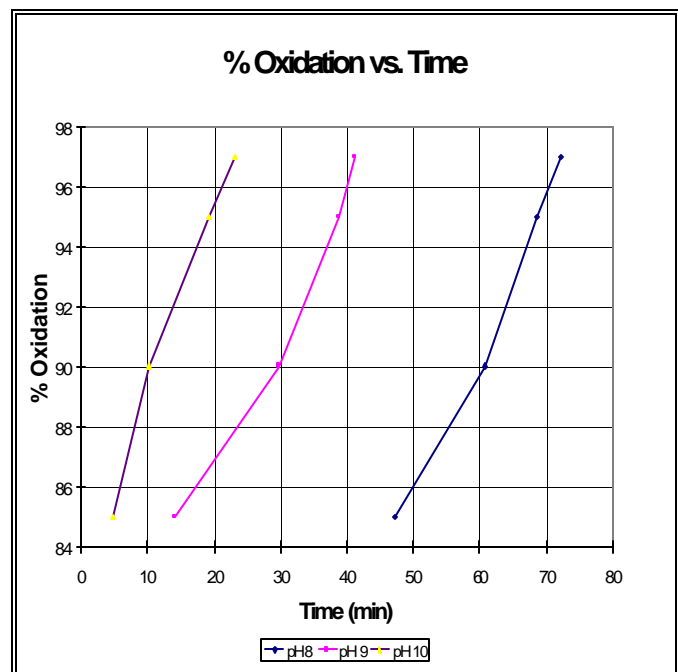


Figure 4-6. Graph F.

pH vs. time. (Graph G)

pH vs. Time	
pH	Time (hours)
11	0
10.7	0.3
10.2	0.5
9.9	0.8
9.6	1.1
9.3	1.5
9	1.8
8.7	2.1
8.5	2.7
8.2	3.9
7.9	4.6
7.6	5
7.4	7.8
7.3	14.3
7.3	24.5

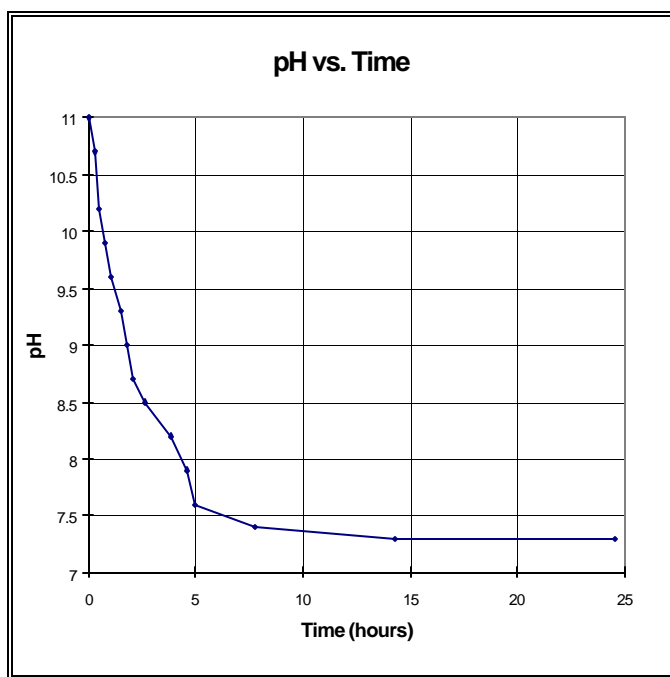


Figure 4-7. Graph G.

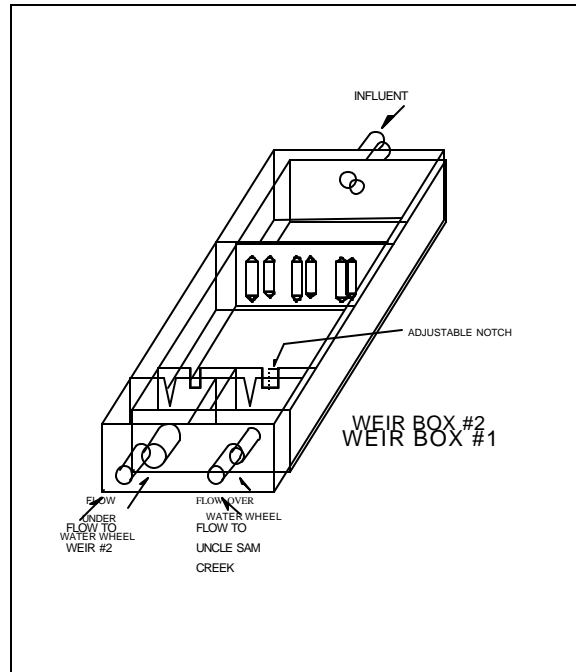


Figure 4-9. Weir #1.



Figure 4-10. Portal and initial oxidation pipe.

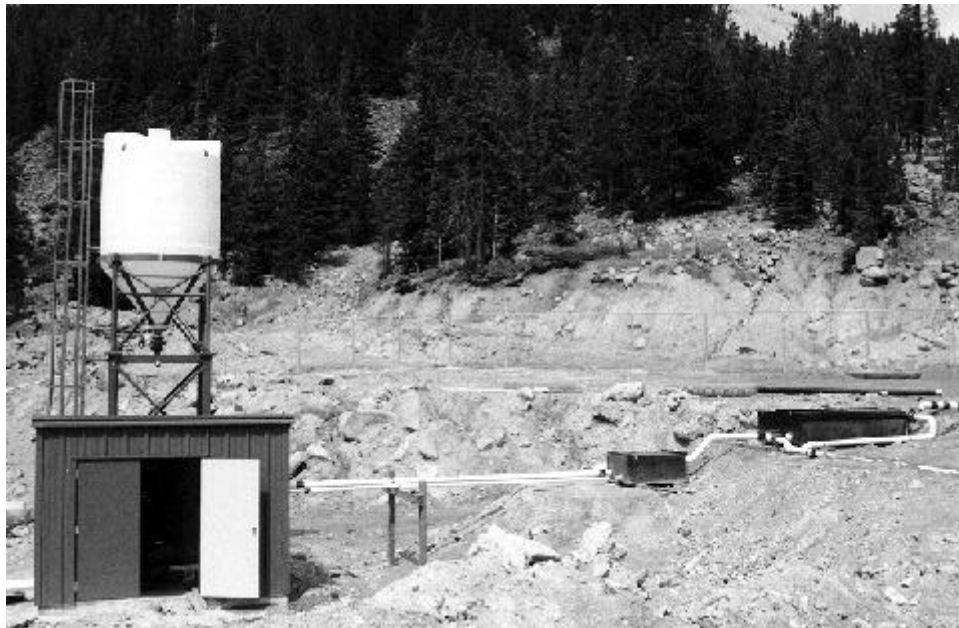


Figure 4-11. AQUA-FIX building and weir boxes at Crystal Mine site.

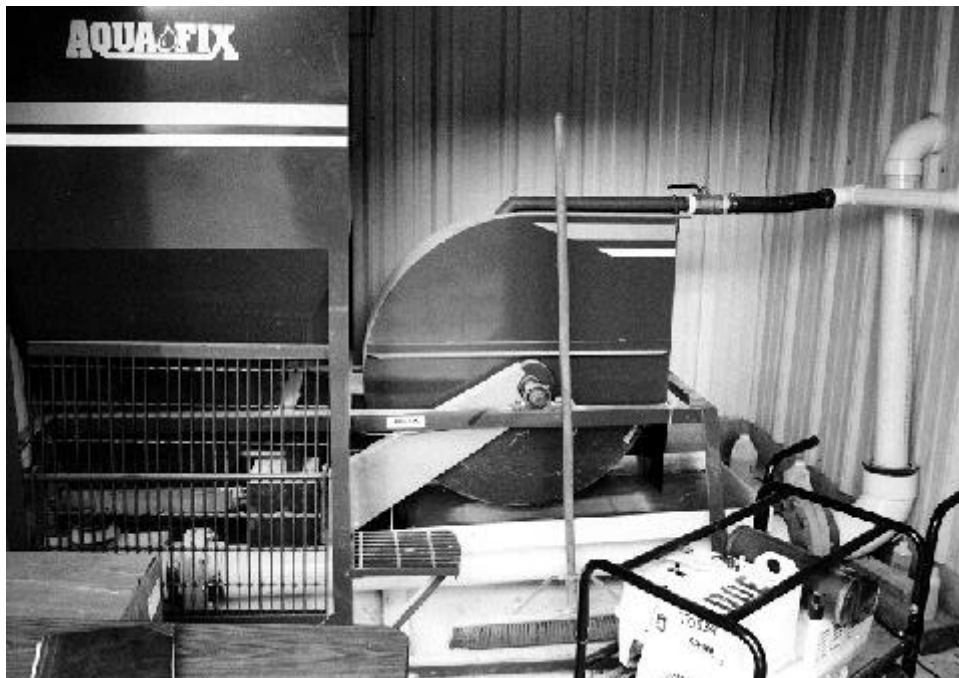


Figure 4-12. AQUA-FIX system.



Figure 4-13. AQUA-FIX building with hopper and pipe carry flow to the ponds.

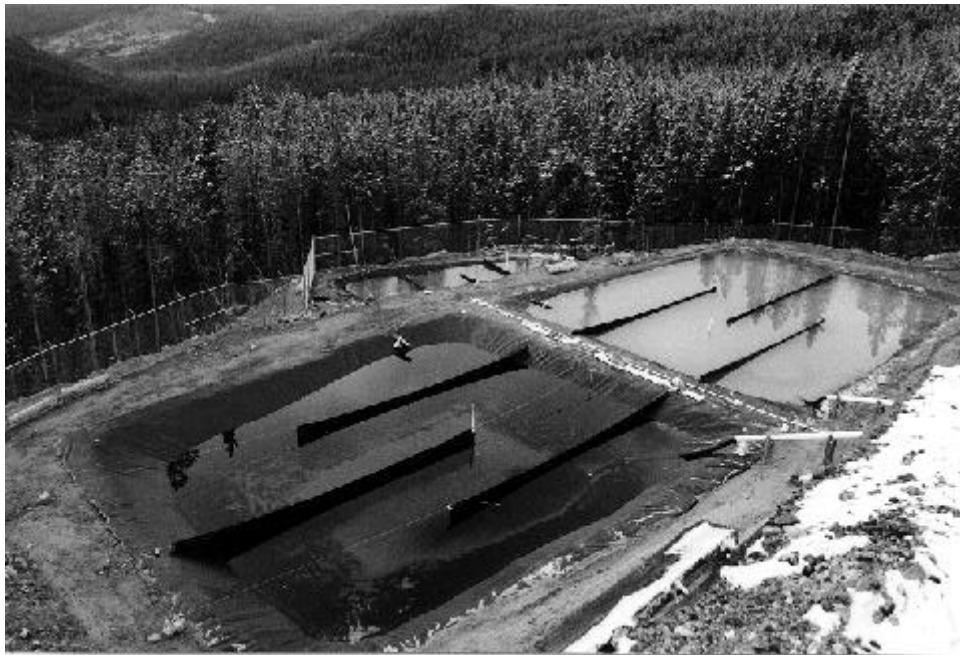


Figure 4-14. Ponds at the Crystal Mine.

Ponds 1 and 2	
Dimension of the pond bottom	40' × 40'
Bottom surface area	1,600 ft <sup>2</sup>
Dimension of the pond top	60' × 60'
Top surface area	3,600 ft <sup>2</sup>
Pond depth	10'
Pond capacity	25,000 CF 925 CY 187,000 gal

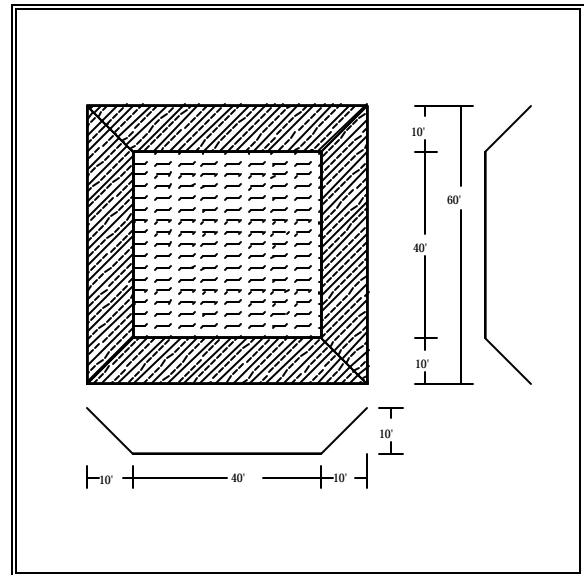


Figure 4-15. Ponds 1 and 2 design.

Pond 3	
Dimension of the pond bottom	25' × 40'
Bottom surface area	1,000 ft <sup>2</sup>
Dimension of the pond top	45' × 60'
Top surface area	2,700 ft <sup>2</sup>
Pond side slope	1:1
Pond depth	10'
Pond capacity	17,500 CF 650 CY 131,000 gal

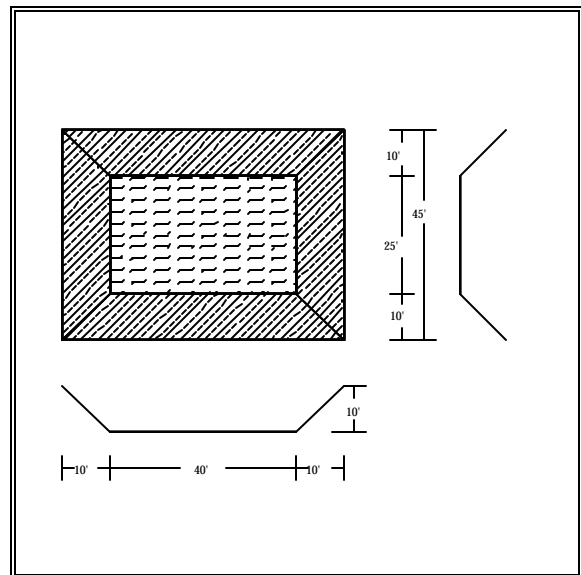


Figure 4-16. Final pond 3 design.

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## 5. Experimental Design

Critical measurements were necessary to achieve the project objectives, and noncritical measurements were used as process indicators and for control.

The pH was measured at the effluent and was critical; other points measured were noncritical and were used for process control to adjust addition of the alkaline reagent.

Flow rate, water wheel revolutions per minute (rpm), pH, oxidation-reduction potential ( $E_H$ ), and temperature were measured on a semi-continuous basis at several points. These measurements were accomplished by placing probes in the flow that transmitted data on a half-hour basis to a data logger. This data was downloaded daily by way of a cellular network and modem. Most of the probes failed within 30 days; therefore, the rpm was the only data that continued to be transmitted throughout the project duration. This data proved valuable throughout the project to distinguish when problems occurred with the reagent feed mechanism. Figure 5-1 shows the probes, and Figure 5-2 shows the computer data logger with the probes.

### 5.1 Technology Demonstration Objectives

The primary objectives of the field demonstration project were to evaluate the reliability of each component and the effectiveness of the process in pH adjustment and heavy metal removal. The process characteristics that were the goals of the field demonstration were:

- removal of metallic constituents; and
- percent operability of the system.

Removal of toxic metallic constituents was quantified by a mass balance between influent and effluent using data from the dissolved metal analysis. Percent operability of the system was

determined by recording the time the system was inoperable due to maintenance or mechanical failure and dividing this time by the total project time. Inoperability was determined by data from the rpm, pH,  $E_H$ , and the removal of metals. When the system was not operating properly, the data showed a lower rpm and pH and a high  $E_H$ .

The goals of the demonstration were to achieve:

- 80% operability of the system;
- the discharge limits in Table 1-2; and
- pH in the effluent between 6 and 8.5.

### 5.2 Factors Considered

Several factors were considered during the development of the experimental design.

Questions that needed to be answered to ensure a successful design were formatted, and a logical decision was derived. The basic primary questions were:

- C What is the unit operation supposed to do?
- C What is known about the unit operation?
- C What is not known about the unit operation?
- C What are the limitations of the unit operation?
- C What process variables of the unit operation need to be measured?
- C What are the interactions of this unit operation with any other unit operation?
- C What laboratory tests will provide the data needed to design and size the field unit operation?

### 5.3 Sampling Design

Quality control sampling formats were designed to illustrate the viability and feasibility of using the technologies contained within the process train to remove many contaminant species from an aqueous-point discharge for up to 2 years. Sample locations and intervals between samples were

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established to aid in the identification of trends and to produce adequate data to evaluate the technology's overall performance. The type of laboratory analysis for each sample was established to ensure adequate data was available to identify the effect of related substances along with the primary elements.

Additional samples were included in each format. These were field samples to be analyzed in the field and used to monitor the day-to-day performance of the technology. The result of the analysis from these samples was recorded in the Demonstration Data Record forms. Noncritical temperature and pH measurements were also recorded in these forms.

The Data Record forms listed the QA samples, field samples, preassigned QA laboratory sample numbers, day and time of each sample, sample location, type of sample, duplicates, and blanks.

Additional samples were included in each format. These were field samples analyzed in the field and used to monitor the technology's day-to-day performance. The result of the analysis from these samples along with  $E_H$ , temperature, weather conditions, site information, process train status, and other observations were recorded on the Demonstration Data Record forms.



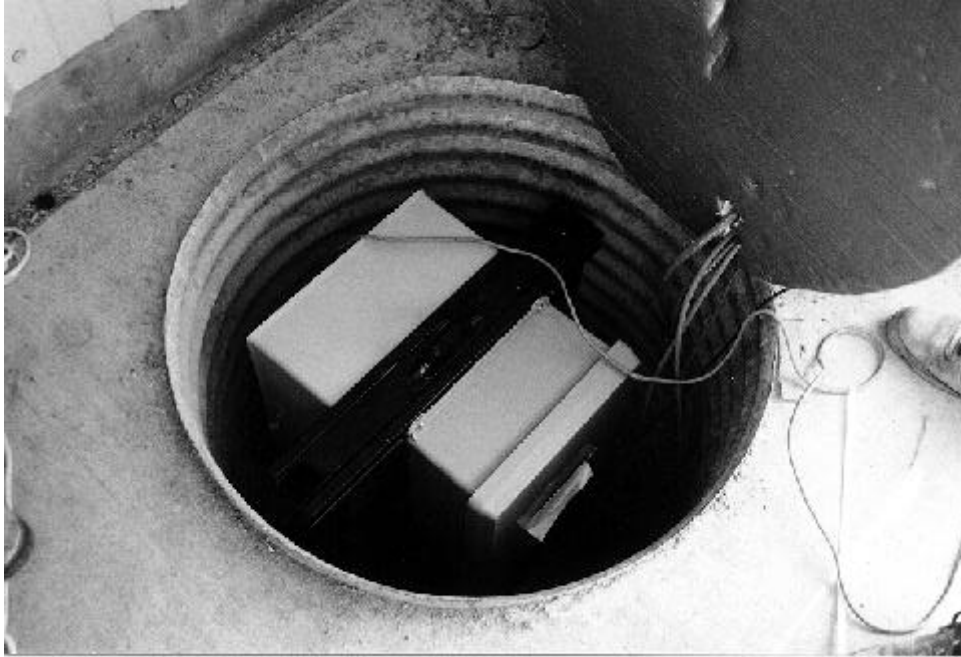


Figure 5-2. Computer data logger and probes.



Figure 5-1. Data probes within sections of the tube.

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## 6. Quality Assurance and Control

The MSE-HKM laboratory is audited annually by the Montana Department of Health and Environmental Sciences. The laboratory is also periodically audited by the MSE Risk Management Division, clients, and the EPA. The laboratory was subjected to performance audits before and during data generation. Audits done before data generation consisted of analyses on standard reference materials. While some data was considered as estimated for various reasons, all the data is usable for the purposes of reporting the results of this field demonstration and detecting the functionality of the technology treatment train.

### 6.1 Review of Laboratory Audits

Several audits were done before and during the Crystal Mine field demonstration:

- laboratory performance audit;
- EPA technical systems review and;
- internal field sampling audit.

#### 6.1.1 Laboratory Performance Audit

The EPA through the State of Montana submits performance evaluation samples to the MSE-HKM laboratory periodically. The results of the performance audit for dissolved metals at the Crystal Mine field demonstration were approved by the EPA on February 1, 1994. All analytes of interest for the Crystal Mine Demonstration were within the acceptable limits. The results are found in Table 6-1.

#### 6.1.2 EPA Technical Systems Review

The EPA conducted a technical systems review of several MWTP projects, including the Crystal Mine field demonstration from November 29 through December 1, 1994. Field activities at the Crystal Mine and laboratory activities associated with the project were reviewed. Only one minor

concern was identified during the technical system review for the Crystal Mine demonstration.

**Minor Issue:** Field personnel did not calculate QC results. When collecting samples, field personnel take field measurements. For measurements considered critical, QC criteria are established. For the Crystal Mine Demonstration, the pH of the drainage water at the adit and the discharge were established as critical measurements. The QC objectives for precision and accuracy should be calculated in the field to ensure the data met the QC objectives.

**Corrective Action:** Field personnel began to calculate and record the QC objectives in the field logbook. In most cases, the pH QC objectives were achieved.

#### 6.1.3 Internal Field Sampling Audit

On October 9, 1995, a field audit of sampling activities was done at the Crystal Mine. The field sampling audit included a review of:

- personnel, facilities, and equipment;
- documentation (chain-of-custody (COC), logbooks);
- calibration of equipment; and
- sampling and measurement procedures.

Samples were collected and measured in the field for dissolved metals,  $E_H$ , and temperature. The pH meter malfunctioned at low temperatures and would not calibrate properly in the field; consequently, a raw pH sample and dissolved metal samples were transported to the MSE-HKM laboratory for analysis. No concerns were identified during the field sampling audit.

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## 6.2 Field And Laboratory Data Validation

MWTP Activity III, Project 1, officially began sampling on September 1, 1994, for Phase II-Field Demonstration of Treating Acid Mine Drainage at the Crystal Mine. The objective of the project was to investigate the effectiveness of using the demonstration process to treat the acid mine drainage at a remote mine site and obtain a high quality effluent.

All of the field and laboratory data for weekly sampling events from August 1994 to June 1996 was evaluated to determine the usability of the data. The final project samples were collected on June 26, 1996.

To determine the effectiveness of the process being demonstrated, several sampling points were designated, and a variety of analyses were assigned to each point. The analyses done were specified in the project-specific QAPP, and each analysis was classified as critical or noncritical. A critical analysis is one that must be done to achieve project objectives. A noncritical analysis is one done to provide additional information about the process being tested. Critical analyses for this project are:

- pH at effluent; and
- dissolved metals at influent and effluent (Al, As, Cd, Cu, Fe, Mn, Pb, Zn).

Noncritical analyses for this project are:

- pH at influent and intermediate points;
- $E_H$ ;
- temperature;
- flow rate;
- total suspended solids (TSS);
- sulfate;
- sludge level;
- sludge total metals;
- sludge Toxicity Characteristic Leaching Procedure (TCLP);

- alkaline reagent addition water wheel rpm;
- dissolved metals at intermediate points (Al, As, Cd, Cu, Fe, Mn, Pb, Zn); and
- total recoverable metals (Al, As, Cd, Cu, Fe, Mn, Pb, and Zn).

The QC objectives for each critical analysis were outlined in the QAPP and were compatible with project objectives and the methods of determination being used. The QC objectives are method detection limits (MDL), accuracy, precision, and completeness. Control limits for each of these objectives were established for each critical analysis. For noncritical analyses, QC objectives were determined by using standard guidelines that exist or by applying reasonable control limits to determine the usability of the data.

### 6.2.1 Validation Procedures

Data generated for all critical and noncritical analyses were validated. The purpose of data validation is to decide the viability of all data generated during a project. Data validation consists of two separate evaluations: analytical and program.

#### 6.2.1.1 Criteria for Analytical Evaluation

An analytical evaluation was done to determine:

- analyses were done within specified holding times;
- calibration procedures were followed correctly by field and laboratory personnel;
- laboratory analytical blanks contained no significant contamination;
- necessary independent check standards were prepared and analyzed at the proper frequency and all remained within control limits;
- duplicate sample analysis was done at the proper frequency and all relative percent differences (RPDs) were within specified control limits;
- matrix spike sample analysis was done at the proper frequency and all spike recoveries

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[percent recovery (%R)] were within specified control limits; and

- data in the report submitted by the laboratory to project personnel can be verified from the raw data generated by the laboratory.

Measurements that fall outside the control limits specified in the QAPP or for other reasons are judged to be outlier were flagged appropriately to indicate the data is judged to be estimated or unusable. All QC outliers for all sampling events are summarized in Table 6-1.

#### **6.2.1.2 Criteria for Program Evaluation**

Program evaluations include an examination of data generated during the project to determine:

- information contained in COC forms is consistent with the sample information in field logs, the laboratory raw data, and laboratory reports;
- samples, including field QC samples, were collected, sent to the appropriate laboratory for analysis, and were analyzed and reported by the laboratory;
- field blanks contain no significant contamination; and
- field duplicate samples show precision of field and laboratory procedures by remaining within control limits established for the RPD.

Program data that was inconsistent or incomplete and did not meet the QC objectives was outlined in the QAPP and flagged appropriately to indicate the usability. Both the analytical and program evaluations consisted of evaluating the data generated in the field and in the laboratory.

### **6.3 Analytical Evaluation**

The analytical evaluation of field and laboratory data was initiated in January of 1995. Several laboratory reports and field data logbooks had already been received by project personnel before data validation was initiated. An effort was made

to validate the data as it was received for the remainder of the project so that if corrective actions were necessary, they could be implemented promptly.

#### **6.3.1 Field Logbook Evaluation**

Field data validation began with an examination of the field logbook created for this project. The field logbook typically contains all of the information that is available about:

- sampling information/conditions; and
- sample treatment/preservation.

#### **6.3.2 Sampling Information/Conditions**

Sampling conditions and information such as weather conditions, date of sampling, and time of sampling should be specified in the field logbook for each sampling event. Sampling information was complete and accurate for all sampling events. Sampling personnel provided information to project personnel about how the overall system was running and what maintenance of the system was required.

#### **6.3.3 Sample Preservation/Treatment**

All of the preservatives required for each analysis are clearly listed in the field logbook; therefore, it is assumed all samples were properly treated/preserved before delivery to the appropriate laboratory, with one exception. On February 22, 1996, the information regarding sample containers, preservatives, and time of collection were not recorded in the logbook; however, COC forms from the same sampling event included the information about preservative and time of collection. The logbook should be amended and dated to include the missing information.

### **6.4 Field Data Validation**

Field data validation was done to determine the usability of the data generated during field activities. The usability was determined by

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verifying that correct calibration procedures of field instruments were followed. In addition, the QC parameters of precision and accuracy calculated in the field were compared with those specified in the QAPP. Any data that fell outside the control must be considered outlier and was flagged appropriately. The following analyses were done in the field:

- pH (critical and noncritical);
- temperature (noncritical);
- $E_H$  (noncritical); and
- sludge level (noncritical).

During extremely cold conditions, field measurements (i.e., pH and  $E_H$ ) could not be made at the demonstration site. These measurements were made at the Western Environmental Technology Office (WETO) or the laboratory. Before this, however, comparisons between field measurements and those made at the site were made. The results were within the QC values for accuracy and precision. Therefore, the measurements made at WETO or the laboratory are considered usable.

#### **6.4.1 pH**

The pH meter was to be calibrated using two known buffer solutions that would bracket the measured pH. To determine the accuracy of the pH meter, a third known buffer in the calibration range was measured twice. Accuracy was defined as the absolute difference between the accepted value of the third known buffer solution and the measured value of the third known buffer solution. Precision was defined in the QAPP as the absolute difference between the two measured values of the third known buffer solution. The QC control limit established for pH measurements for both precision and accuracy was  $\pm 0.1$  pH unit.

For each sampling event, calibration of the pH meter was done correctly, with one exception. For the June 6, 1996, sampling event, a reading for

the pH 7 buffer is not recorded in the logbook. Since it is unclear if the pH meter was calibrated properly, the pH values for this sampling event are flagged "R" as unusable.

Although sampling personnel either did not calculate the QC control limits or calculated them incorrectly for pH analysis, enough information was available to determine the pH measurements were within control limits, with two exceptions. For the first sampling event (September 8, 1994), no midrange calibration check was performed, making it impossible to determine the precision or accuracy of the measurements. Therefore, pH data from this event should be flagged "R" as unusable. During the December 12, 1994, and January 25, 1995, sampling events, the accuracy of the pH meter was outside control limits. The pH readings from these events should be flagged "J" as estimated. If the precision and accuracy calculations had been performed on site, recalibration of the pH meter could have avoided these data points from being judged outlier. Sampling personnel were notified of this problem, and corrective action was implemented by calculating the precision and accuracy for all previous and subsequent sampling events.

Similar confusion about the calculation of precision and accuracy of pH readings were observed after sampling personnel changed on February 22, 1996; however, enough information was available to determine the precision and accuracy of the pH readings. On May 9, 1996, pH values were flagged "J" for not meeting the accuracy objective. On June 13, 1996, pH values were flagged "J" because a duplicate reading was not done on the midrange buffer solution, making it impossible to decide the precision of the measurements.

#### **6.4.2 Temperature**

The pH meter was also used to determine temperature using the thermistor contained in the pH probe. The thermistor was calibrated against a

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mercury thermometer in the sample coolers at the laboratory at roughly 4 EC; the typical temperature of the water in the field is very close to 4 EC. The temperature calibration procedure was performed for all sampling events until the sampling personnel change.

For all sampling events from February 22, 1996, to June 26, 1996, calibration of the pH temperature sensor was not recorded. All temperature readings from February 22, 1996, to June 26, 1996, were flagged "J" as estimated.

#### **6.4.3 $E_H$**

Because  $E_H$  is not a critical parameter in the QAPP, there were no specific QC objectives assigned to this analysis. However, the data generated was examined to determine if the instrument was properly calibrated. The calibration information for  $E_H$  was documented in the field logbook for each sampling event. All  $E_H$  data was considered usable. On March 28, 1996, sampling personnel indicated the  $E_H$  meter was not available; therefore,  $E_H$  data is not available for that sampling event.

#### **6.4.4 Sludge Level**

Sludge level readings were recorded when possible. On several occasions, the ponds were cloudy or snow covered, and the sludge level could not be read. When a sludge level was not recorded, sampling personnel would record the reason for no measurement. All sludge level data was considered usable.

### **6.5 Laboratory Data Validation**

Laboratory data validation was done to determine the usability of the data generated by the MSE-HKM laboratory for the project. The following analyses were done in the laboratory:

- sulfate (noncritical);
- TSS (noncritical);
- sludge total metals (noncritical);

- sludge TCLP (noncritical); and
- dissolved metals (critical and noncritical) and total recoverable metals (noncritical).

Laboratory data validation was performed using the *EPA Contract Laboratory Program National Functional Guidelines for Inorganics Data Review* (Ref. 1) as a guide, where applicable, to each individual analysis. For critical analyses, the QC criteria outlined in the QAPP were also used to identify outlier data and to determine the usability of the data for each analysis. When data validation was initiated, the MSE-HKM laboratory did not send sufficient information to complete a thorough data validation on the nonmetal, wet chemistry analyses. The QA/QC summaries submitted with the reports lacked information about calibration blanks and raw data making sample result verification impossible. An informational request was made to the laboratory in January 1995, and laboratory personnel responded by submitting all of the requested information. Once the information was received, data validation of all analyses was completed, and all subsequent laboratory reports included the necessary information for data validation.

#### **6.5.1 Sulfate**

Results of sulfate analysis for sampling on May 22, 1995, were flagged due to low matrix spike recovery. The spike recovery was only 58%, and to be considered acceptable, the spike recovery should be within the 75%-125% range. Sulfate results for the November 15, 1995, samples were qualified for a high spike recovery of 131%. The samples associated with the low and high spike recoveries were flagged "J" as estimated and are summarized in Table 5-1.

#### **6.5.2 Total Suspended Solids**

The reported result for a sample analyzed for TSS (CM-1A sampled on October 4, 1994) was 800 mg/L. All other TSS results have been

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-100 mg/L. The result for the field duplicate was 84 mg/L. The result from the original sample is not explainable when compared with the historical data or the field duplicate result. To ensure laboratory personnel did not enter the wrong result in the computer, the raw data was examined. The results of the samples were recalculated, and the result was verified to be 800 mg/L. The result is incorrect and flagged "X". This value was excluded from further interpretation.

The TSS for samples collected on July 24, 1995, exceeded the analysis holding times. The holding time for TSS analysis is 7 days, and TSS samples were analyzed 80 days after receipt. The TSS results were flagged "J" as estimated. All TSS data requiring qualifiers is summarized in Table 5-1.

### **6.5.3 Metals Analysis**

Dissolved metals analysis was classified as critical in the QAPP, while total recoverable and total metals analyses were classified as noncritical. However, all metals analyses were evaluated using the QC criteria specified in the QAPP for dissolved metals and the *EPA Contract Laboratory Program National Functional Guidelines for Inorganics Data Review* (Ref. 1). All metals results are considered usable; however, some samples had to be flagged "J" as estimated, for certain analytes. Total metals analysis was done on sludge TCLP samples for the project because the samples were insufficient for analyses. The spike recoveries, duplicate RPDs, serial dilution recovery, and laboratory control sample outside control limits for various analytes is available on request.

All metals data requiring qualification are summarized in Table 5-1. Once the analytical portion of the evaluation was completed, the program evaluation was initiated.

## **6.6 Program Evaluation**

The program evaluation focused on the following areas:

- COC procedures;
- sampling and data completeness;
- field blanks; and
- field duplicates.

### **6.6.1 Chain-of-Custody Procedures**

All information provided in the COC forms for this project is complete and accurate.

### **6.6.2 Sampling and Data Completeness**

All samples were collected when possible and analyzed for the requested analyses on the COC forms. For batch C2369, consisting of samples collected on June 26, 1996, Ca and Mg values were reported while Cu and Mn values were not reported. The situation was rectified, and the Cu and Mn values were reported to the Project Manager.

### **6.6.3 Field QC Samples**

All field QC samples were collected at the proper frequency.

### **6.6.4 Field Blanks**

None of the field blanks collected for the project showed significant contamination, with the following exceptions. The field blank for dissolved metals sampled on September 4, 1994, and April 16, 1996, was above the Contract Required Detection Limit (CRDL) for Zn, and the field blank from the October 17, 1994, sampling event was above the CRDL for Zn and Cd; however, the associated sample concentrations for metals analyses were at least 10 times the contamination found in the blanks. Consequently, the contamination had no significant impact on the Zn or Cd concentrations for the samples. Contract Laboratory Program (CLP) QC criteria allow blank contamination above the CRDL if the sample concentration is greater than 10 times the

contamination found in the blank; therefore, no action was taken.

The field blank for TSS sampled September 8, 1994, showed significant contamination

- dissolved Pb duplicates sampled October 26, 1995, of batch C2032, RPD=144.1%; and
- dissolved Cu and Pb duplicates were sampled December 7, 1995, of batch C2103 showed differences greater than the CRDL.

The Cu and Pb values for the associated batches are flagged "J" as estimated in Table 5-1.

(above 2 times the MDL) and TSS data was flagged "J" as estimated.

#### **6.6.5 Field Duplicates**

Field duplicates showed good agreement to the original samples, with the following exceptions:

Table 6-1. Performance evaluation sample.

Analyte	Reported Results (Fg/L)	True Value (Fg/L)	Acceptable Range (Fg/L)	Action
Aluminum	1,420	1,400	1,260 - 1,510	Acceptable
Arsenic	38.8	39.5	33.1 - 45.1	Acceptable
Cadmium	50.2	49.0	39.2 - 58.8	Acceptable
Copper	1,908	1,900	1,710 - 2,090	Acceptable
Iron	Not requested	Not Applicable	Not Applicable	Not Applicable
Manganese	64.8	63.3	56.7 - 67.7	Acceptable
Lead	78.1	78.7	55.1 - 102	Acceptable
Zinc	2126	2,090	1,920 - 2,240	Acceptable



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## 7. Results and Discussion

The complete data set as derived from the Remote Mine Site Demonstration is found in Appendix A. A selected set of this data is listed within sections of the document.

Dissolved metal chemistry data for the acidic, metal-laden drainage that emanated from the lower portal of the Crystal Mine during the demonstration is shown in Table 6-1. This table also contains the dissolved metal chemistry data for the treated water that discharged from the technology treatment train during the extent of the demonstration.

Table 7-1 gives the dissolved chemistry field data, and graphically displays the results of the treatment technology train for each of the eight elements observed throughout the demonstration. These eight elements are: Al, As, Cd, Cu, Fe, Pb, Mn, and Zn. Contained in these figures is the mine adit effluent concentration (influent), the treatment train effluent concentration (effluent), and the boundary condition for each element.

As stated within Section 6, all data reported was checked for validity concerning the requirements of the project-specific QAPP.

The intent of this project was to design, construct, and test the operation and function of a technology treatment train that used the AQUA-FIX technology to add an alkaline reagent to the acidic, metal-laden water discharging from the lower adit of the Crystal Mine. The specific technology goal was to raise the pH of the process train by the addition of the alkaline reagent (pebble quicklime), thereby removing dissolved toxic metals from the effluent stream as metallic hydroxides and oxides. The operational goal was to have the treatment train operate with minimal operator assistance throughout the demonstration while maintaining the quality of the discharge water.

Before the demonstration, acidic, metal-laden waters discharged from the lower adit of the Crystal Mine directly into Uncle Sam Creek. This discharge had caused severe damage to this stream and its ability to support aquatic life forms. During the demonstration, water of variable quality discharged from the treatment train. However, the quality of the discharge water was at all times superior to the water that was discharging directly from the mine portal.

The AQUA-FIX technology is a water wheel-driven alkaline reagent feeder. Laboratory test work confirmed that by raising the pH of the acidic solution to a value of approximately 10, the concentrations of dissolved toxic metals would reduce to values near or below the boundary conditions applied during this demonstration. The field demonstration showed the technology train is not capable of operating for more than approximately 2 weeks without the assistance of a trained operator to adjust the operation of the process.

### 7.1 Data Interpretation

The Remote Mine Site Demonstration operated in the field for approximately 2 years. During this time, the field operation was monitored by sampling on a weekly basis. Table 7-2 contains the percentage of the samples, on an elemental basis, that satisfied the conditions for the demonstration.

The concentration of Pb being discharged by the system met the boundary conditions 99% of the time. However, the concentration of Pb within the Crystal Mine drainage is extremely low and was lower than the boundary conditions for large periods during the demonstration.

The concentration of Zn being discharged by the system met the boundary conditions only 44% of

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the time. This was largely because the pH of the treated water must reach a value near 10 to successfully remove Zn to the level of the boundary conditions. This value of pH was only reached 44% of the time during operation.

The concentrations of Al, Pb, and Cu being discharged by the system met the boundary conditions 64%, 57%, and 52% of the time. This was largely because these three elements require the pH of the treated water to reach a value near 7 to successfully reach the level of the boundary conditions.

## **7.2 Operation Interpretation**

As can be seen from the data presented within Section 5, the treatment train failed to operate as designed for long periods throughout the demonstration. The initial demonstration was meant to last for 1 year of field operation. During the first year of operation, the system performed as designed only 36% of the time (131 days). Conversely, during the first year of operation, the process failed to perform as designed 64% of the time (234 days). The majority of the time (184 days or 79%) that the system did not operate as designed, the failure was due to a lack of knowledge and job skills by the monitoring staff assigned to the demonstration. The remaining days the system did not operate as designed (60 days or 21%), the failures were largely due to plugging of the alkaline reagent within the throat of the AQUA-FIX. This problem continued to plague the project until the problem was properly diagnosed in December of 1995.

Due to the poor operation of the process train within the first year of the demonstration, the decision was made to better train the individuals that were responsible for the weekly monitoring of the process train and then continue to operate the system for a second year.

During the second year of operation, the system performed as designed 70% of the time (209 days). Conversely, during the second year of operation, the process failed to perform as designed 30% of the time (91 days). Lack of knowledge by the operational team accounted for 37 of the 91 failed days or 41% of the failures. It should also be stated that these failures occurred in the first two weeks of the second year and during a crew change in December of 1995.

On March 14 and again on May 23, 1996, during the second year of operation, the lower portal of the Crystal Mine collapsed. These events resulted in the process train being clogged with debris and/or being bypassed by the acidic water. This clogging of the system and intermittent flow of water resulted in the failure of the system for a total of 35 days or 38% of the downtime during the second year of operation.

The remaining days that the system did not operate as designed (19 days or 21%) during the second year was largely due to plugging of the alkaline reagent within the throat of the AQUA-FIX.

Reagent plugging the throat of the AQUA-FIX was caused by a combination of two factors. The first was a function of the design of the AQUA-FIX unit itself. The AQUA-FIX unit was designed with an auger that was shorter than the tube encasing the auger by 6 inches. This caused the reagent to be deposited in a pile within the tube at the end of the auger. This pile would be moved through the tube by the build up of more reagent on the end of the pile. Therefore, the end of the auger encasing tube near the outlet was largely choked with reagent on a constant basis. The second factor that enhanced the clogging of the AQUA-FIX throat was a breeze that moved up the pipeline that conveyed the water from the AQUA-FIX building to the first set of settling ponds. This pipeline has been called the final

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oxidation unit within this document. The pipeline faced downhill to the south and acted like a chimney in that it channeled the breeze into the AQUA-FIX building and the throat of the AQUA-FIX unit. It should be stated that the throat of the AQUA-FIX was less than 2 feet from the beginning of the pipeline in question. The breezes coming into the AQUA-FIX throat helped the reagent to acquire moisture that enhanced the previously described reagent caking. The clogging of reagent within the throat of the AQUA-FIX did not allow reagent to enter the acidic stream. This caused the pH of the effluent to decrease rapidly. To correct the clogging problem, the auger on the AQUA-FIX was lengthened to prevent the reagent from building up within the auger tube. In addition, a cowling was installed that prevented breezes from entering the AQUA-FIX building by means of the final oxidation pipeline.

Aside from the aforementioned operational problems, for the majority of the demonstration, the entire adit flow was treated per a request by the client. This caused considerable strain on the operation of the system as it was initially designed to accommodate only one-half of the adit flow.

The piping was more than half full, the sludge built up in the ponds at twice the design rate, the reagent was used at twice the design rate, and the water wheel rotational speed was twice as fast as designed. All this caused considerable water splatter and ice buildup within the demonstration building.

Finally, it should be stated that on several occasions, the previously mentioned plugging problem occurred on a weekly basis. On several occasions, operators went to the site to sample and would find the system had malfunctioned due

to reagent plugging. The operator would repair the system and sample the influent and effluent. The effluent sample taken during these occasions would seldom meet the boundary conditions. Several days later, the system would plug again, and the following week, the operators would again find the system nonoperational. Samples taken would fail to meet the boundary conditions even though the system had operated as designed for several days between sampling dates. This was shown by the one portion of the remote monitoring system that remained viable throughout the demonstration, i.e., the water wheel speed indicator.

Table 7-3 is the summary of operational costs of the technology treatment system. As can be seen from the table, the most expensive portion of the operation is the removal and disposal of the sludge produced during the processing of the acidic, metal-laden water. The sludge produced from the Crystal Mine operation was not toxic in that it met the TCLP test. Had this sludge failed TCLP, the cost of disposal of the material would have been much higher. In addition, the sludge was hauled approximately 1 mile and disposed in the upper workings of the Crystal Mine. A longer haul to dispose of the sludge would have added to disposal costs.

The cost of the reagent used to treat the water, which is normally considered as the "cost of treatment," is by far the lowest of the unit costs and is generally not consequential relative to the overall cost of the operation.

Table 7-1. Dissolved chemistry field data.

Dissolved Chemistry Field Data for the Crystal Mine Project														
Date	Pt	pH	E <sub>H</sub>	Temp	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	SO4	TSS
-----	--	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	----
09/01/94	1	3.01	3.89	5.4	12.30	1.14	0.86	13.00	43.50	13.90	0.28	64.50	363	49
	6	11.8	86	9.8	1.09	0.03 <sup>U</sup>	0.004	0.006	0.01	0.003	0.04 <sup>U</sup>	0.37 <sup>J</sup>	---	---
09/08/94	1	3.38	412	5.6	12.90	1.12	0.87	13.40	44.10	14.40	0.30	65.40	431	162
	7	11.8	128	13.3	0.91	0.03 <sup>U</sup>	0.004	0.006	0.01 <sup>U</sup>	0.002	0.04 <sup>U</sup>	0.23	406	128 <sup>U</sup>
09/14/94	1	---	---	---	12.90	1.11	0.91	13.40	45.20	15.00	0.31	67.30		
	7	4.88	406	8.3	0.776	0.03 <sup>U</sup>	0.21	1.91	1.87	3.68	0.04	14.00		
09/19/94	1	---	---	---	12.20	0.93	0.86	12.60	41.10	14.10	0.30	63.10		
	7	10.9	432	9.3	0.05 <sup>U</sup>	0.03 <sup>U</sup>	0.004	0.01 <sup>U</sup>	0.02	0.01	0.04 <sup>U</sup>	0.05		
09/26/94	1	3.11	---	---	12.90	0.89	0.92	13.30	43.70	15.30	0.29	67.50		
	7	11.6	---	8.9	0.71 <sup>J</sup>	0.03 <sup>U</sup>	0.004	0.01 <sup>U</sup>	0.03	0.01	0.04 <sup>U</sup>	0.02		
10/03/94	1	---	482	4.6	12.00	0.74	0.87	12.50	40.90	14.80	0.27	65.00	390	800 <sup>X</sup>
	7	11.0	---	2.0	1.21	0.03 <sup>U</sup>	0.004	0	0.03	0.02 <sup>U</sup>	0.02	0.17	464	9
10/10/94	1				11.4	0.46	0.86	11.8	37.5	14.2	0.256	61.3		
	7				0.21	0.03 <sup>U</sup>	0 <sup>U</sup>	0	0.01 <sup>U</sup>	0.01 <sup>U</sup>	0.02 <sup>U</sup>	0.017		
10/21/94	1	3.20	452	4.6	10.20	0.43	0.81	10.80	33.80	13.90	0.24	59.00		
	5	4.53	393	3.2	2.79	0.03 <sup>U</sup>	0.83	7.90	10.90	14.20	0.02 <sup>U</sup>	58.00		
10/31/94	1	3.14	441	4.3	9.84	0.73	0.83	10.40 <sup>J</sup>	36.80	14.50	0.25	58.70	408	15
	5	5.92	383	3.5	0.09	0.03	0.15	0.14	0.28	6.90	0.02	3.70	417	4
11/07/94	1	3.09	448	4.0	10.20	0.54	0.85	10.90 <sup>J</sup>	34.60	14.50	0.24	59.80		
	5	6.85	341	2.9	0.02	0.03	0.13	0.01	0.02	7.14	0.02	2.62		
11/14/94	1	3.03	492	4.7	9.73	0.25	0.86	10.50	32.00	14.30	0.24	58.50		
	5	4.98	365	3.2	0.02 <sup>U</sup>	0.03 <sup>U</sup>	0.62	0.44	0.06	11.60	0.26	26.80 <sup>J</sup>		
12/12/94	1	2.95 <sup>J</sup>	460	---	8.61	0.15	0.79	9.37	27.60	14.10	0.24	56.40	381	31
	5	3.71 <sup>J</sup>	371	3.2	8.48	0.03 <sup>U</sup>	0.83	10.00	14.50	14.70	0.15	60.10	418	4
12/19/94	1	2.94	441	4.2	8.78	0.18	0.82	9.49	28.40	14.50	0.21	57.80		
	5	3.80	371	3.1	8.78	0.11	0.83	9.88	23.30	14.50	0.22	58.50 <sup>J</sup>		
12/29/94	1	3.27	471	4.4	8.28	0.13	0.81	9.99	26.30	14.30	0.21	56.30		
	5	3.85	208	2.1	0.02 <sup>U</sup>	0.03 <sup>U</sup>	0.14	0.01	0.03	6.87	0.02 <sup>U</sup>	2.49		
01/03/95	1	3.45	446	3.7	8.28	0.13	0.81	8.99	26.30	14.30	0.21	56.30		
	5	10.2	169	2.2	0.19	0.03 <sup>U</sup>	0.004	0.002	0.03	0.005	0.02 <sup>U</sup>	2.49		
01/09/95	1	3.23	510	4.6	7.75	0.12	0.78	8.51	25.10	13.80	0.21	54.60	376	35
	5	10.2	188	2.4	0.15	0.03 <sup>U</sup>	0.004	0.002	0.009	0.006	0.02 <sup>U</sup>	0.08 <sup>J</sup>	368	21
01/25/95	1	3.11 <sup>J</sup>	507	4.9	8.06	0.08	0.78	8.57	24.60	14.10	0.21	56.80		
	5	3.31 <sup>J</sup>	427	3.3	7.87	0.04 <sup>U</sup>	0.85	8.97	15.30 <sup>J</sup>	14.80	0.23	58.10		
01/30/95	1	3.15	456	3.7	7.30	0.11	0.76	7.93	24.50	13.60	0.22	51.70		
	5	5.30	290	2.7	0.08	0.04 <sup>U</sup>	0.59 <sup>J</sup>	0.93	0.73	11.70	0.04 <sup>U</sup>	33.10		
02/06/95	1	3.28	442	4.7	7.83	0.06	0.80	8.31	23.50	14.60	0.22	55.90		
	5	4.39	291	2.8	1.28	0.04 <sup>U</sup>	0.76	5.84	9.08	13.60	0.04 <sup>U</sup>	50.20		
02/15/95	1	3.39	459	3.8	6.84	0.07	0.74	7.39	20.20	13.60	0.22	52.00	367	21

Table 7-1. Dissolved chemistry field data.

Dissolved Chemistry Field Data for the Crystal Mine Project														
Date	Pt	pH	E <sub>H</sub>	Temp	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	SO <sub>4</sub>	TSS
	5	3.20	454	1.5	5.66	0.04 <sup>U</sup>	0.662 <sup>J</sup>	6.15 <sup>J</sup>	13.9	12.2	0.169 <sup>J</sup>	45.6	390	49
03/02/95	1	3.35	438	4.3	6.91	0.07	0.75	7.40	21.10	13.70	0.19	53.20		
	5	5.55	220	2.3	0.03 <sup>U</sup>	0.04 <sup>U</sup>	0.14	0.002	0.01 <sup>U</sup>	5.33	0.04 <sup>U</sup>	1.45		
03/06/95	1	3.14	428	---	5.97	0.05	0.66	6.51	19.60	12.10	0.15	46.20		
	5	6.79	353	---	0.03 <sup>U</sup>	0.04 <sup>U</sup>	0.01	0.002	0.01 <sup>U</sup>	1.23	0.04 <sup>U</sup>	0.05		
03/13/95	1	3.15	481	3.8	6.49	0.05	0.72	7.06	19.20	13.10	0.19	49.80		
	5	8.57	196	2.8	0.03 <sup>U</sup>	0.04 <sup>U</sup>	0.02	0.002	0.01 <sup>U</sup>	1.56	0.04 <sup>U</sup>	0.05		
03/20/95	1	3.39	423	4.8	6.45	0.10	0.72	6.90	22.60	13.50	0.20	51.20	363	16
	5	4.40	330	3.0	1.15	0.04 <sup>U</sup>	0.26	1.88	3.26	6.51	0.04 <sup>U</sup>	14.40	366	32
04/03/95	1	3.37	416	4.8	5.74	0.04 <sup>U</sup>	0.68	6.36	20.90	12.60	0.20	47.50		
	5	3.37	424	3.4	4.96	0.04 <sup>U</sup>	0.60 <sup>J</sup>	5.51 <sup>J</sup>	15.20 <sup>J</sup>	11.00 <sup>J</sup>	0.15	41.50		
04/10/95	1	3.20	466	5.0	5.82	0.05	0.68	6.43	20.20	12.60	0.21	47.20		
	5	5.22	441	2.9	0.03	0.04	0.44	0.08	0.01	9.36	0.04	24.30		
04/17/95	1	3.18	467	4.5	7.03	0.12	0.71	7.89	24.90	13.20	0.22	49.90		
	5	5.43	303	3.6	0.04	0.03 <sup>U</sup>	0.45	0.51	0.55	9.67	0.02 <sup>U</sup>	24.60		
04/24/95	1	3.18	451	4.9	7.31	0.08	0.75	8.15	23.40	13.60	0.23	52.00	372	69
	5	4.76	351	3.2	0.19	0.03	0.69	4.73	8.96	12.60	0.02	45.70	388	6
05/01/95	1	3.46	453	4.9	6.93	0.14	0.70	7.43	22.80	13.20	0.21	47.90		
	5	4.61	350	4.2	0.16	0.03 <sup>U</sup>	0.63	2.26	3.56	12.50	0.02 <sup>U</sup>	38.40		
05/08/95	1	3.14	----	4.9	7.80	0.25	0.67	8.71	25.90	12.40	0.20	46.00		
	5	4.99	----	4.3	0.10	0.03 <sup>U</sup>	0.49	0.85	1.37	10.40	0.02 <sup>U</sup>	27.30		

Table 7-1. Dissolved chemistry field data.

Dissolved Chemistry Field Data for the Crystal Mine Project														
Date	Pt	pH	E <sub>H</sub>	Temp	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	SO <sub>4</sub>	TSS
05/15/95	1	2.48	510	5.0	20.50	46.80	0.93	49.60	256.0	12.70	0.76	73.40		
	5	2.76	508	5.6	16.70	18.00	0.87	32.90	146.0	12.40	0.57	70.10		
05/22/95	1	2.26	511	5.3	42.70	62.70	1.05	94.30	347.0	10.40	0.87	90.80	1360 <sup>J</sup>	92
	5	2.27	516	5.4	48.00	67.60	1.10	106.0	386.0	11.4	0.95	96.50	1460 <sup>J</sup>	4 <sup>U</sup>
06/02/95	1	2.63	522	5.6	28.20	25.00	0.76	46.50	196.0	8.86	0.52	68.70		
	5	2.64	517	6.6	31.40	25.30	0.79	50.20	202.0	8.93	0.57	69.60		
06/12/95	1	2.63	511	5.3	23.90	15.70	0.79	36.00	140.0	10.60	0.43	67.10		
	5	2.72	511	6.6	25.10	12.60	0.81	35.60	128.0	10.90	0.44	66.30		
06/19/95	1	2.77	505	5.4	24.70	14.50	0.92	34.40	141.0	11.40	0.48	77.90		
	5	2.74	483	6.0	25.70	11.10	0.89	34.50	124.0 0	11.00	0.45	74.50		
06/26/95	1	2.73	502	5.7	24.30	8.46	0.99	30.10	115.0 0	13.90	0.40	81.50	815	95
	5	2.97	489	7.6	24.40	3.09	1.09	31.20	69.60	14.40	0.29	83.20	771	92
07/05/95	1	2.85	490	5.5	22.20	5.38	1.00	26.10	95.50	14.40	0.51	81.40		
	5	9.87	180	7.4	0.95	0.03 <sup>U</sup>	0.004	0.02	0.04	0.01	0.02 <sup>U</sup>	0.26		
07/12/95	1	----	----	----	----	----	----	----	----	----	----	----	----	----
	5	3.17	454	8.8	12.20	0.14	0.82	15.90	7.63	11.90	0.15	61.50		
07/17/95	1	2.74	437	5.9	23.80	6.42	1.03	28.90	104.0	14.60	0.35	85.20		
	5	2.79	552	7.3	22.40	5.78	1.05	27.20	95.50	14.00	0.35	82.60		
07/24/95	1	3.39	474	5.7	24.00	4.79	0.98	27.50	97.90	15.50	0.36	86.80	591.0	11 <sup>J</sup>
	5	4.64	408	9.8	2.35	0.06	0.77	8.99	5.94	11.40	0.04	53.40	669.0	12 <sup>J</sup>
07/31/95	1	2.98	515	5.6	20.40	3.88	1.06	23.20	79.40	14.60	0.34	81.90		
	5	3.04	535	6.2	19.20	1.84	0.98	22.10	55.30	14.30	0.27	78.80		
08/07/95	1	2.93	503	5.5	19.50	2.99	1.05	22.00	72.50	14.50	0.34	79.40		
	7	12.0	82	14.0	0.11	0.03	0.00	0.00	0.02	0.01	0.04	1.17		
08/14/95	1	3.26	480	5.6	18.30	2.10	1.03	20.40	65.10	14.60	0.32	77.90		
	7	10.4	299	11.3	0.32	0.03	0.00	0.00	0.03	0.04	0.04	0.03		
08/21/95	1	2.97	488	6.3	17.00	1.58	0.98	18.70	57.70	14.20	0.29	73.30	497	50
	7	3.70	439	12.6	6.55	0.04	0.54	8.61	8.74	7.94	0.10	39.30	558	5
08/28/95	1	2.90	560	5.8	17.60	1.49	0.97	18.70	59.10	14.90	0.33	75.10		
	7	3.15	509	8.4	13.90	0.11	0.77	14.60	19.50	11.90	0.19	60.00		

Table 7-1. Dissolved chemistry field data.

Dissolved Chemistry Field Data for the Crystal Mine Project														
Date	Pt	pH	E <sub>H</sub>	Temp	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	SO <sub>4</sub>	TSS
09/06/95	1	2.93	377	5.7	16.50	1.17	0.94	17.40	53.40	14.30	0.29	70.80		
	7	12.7	160	7.9	0.13	0.03	0.00	0.06	0.02	0.01	0.04	1.31		
09/11/95	1	3.48	427	5.8	16.70	1.75	0.93	17.80	57.40	14.10	0.27	72.20		
	7	4.43	431	10.2	5.87	0.03	0.48	7.33	6.44	7.41	0.05	35.50		
09/18/95	1	2.84	461	5.2	15.70	1.28	0.88	16.50	51.90	13.90	0.28	67.90	535	69
	7	12.0	112	9.0	0.46	0.03	0.01	0.00	0.02	0.01	0.04	0.64	507	24
09/25/95	1	3.00	519	----	14.80	1.02	0.87	15.80	48.60	14.00	0.27	66.70		
	7	11.5	178	----	0.27	0.03 <sup>U</sup>	0.003	0.01	0.03	0.005	0.04	0.91		
10/02/95	1	3.21	456	5.5	14.80	0.90	0.89	15.60	48.40	14.40	0.27	67.60		
	7	12.3	72	5.6	0.35	0.03 <sup>U</sup>	0.003	0.01	0.02	0.005	0.04 <sup>U</sup>	0.97		
10/09/95	1	3.11	448	4.9	14.20	0.65	0.88	15.00	45.90	14.30	0.25	66.30		
	7	12.3	172	3.9	0.09	0.03 <sup>U</sup>	0.003	0.004	0.02	0.005	0.04 <sup>U</sup>	0.25		
10/16/95	1	3.17	460	4.8	13.70	1.02	0.86	14.90	47.00	14.10	0.30	66.40	490	41
	7	11.8	99	6.0	0.69	0.04 <sup>U</sup>	0.004	0.01	0.01	0.003	0.03 <sup>U</sup>	0.06	506	13
10/26/95	1	3.02	485	4.0	13.70	0.56	0.91	17.20	41.40	15.00	1.86 <sup>J</sup>	69.10		
	7	4.65	389	2.1	8.93	0.04 <sup>U</sup>	0.70	10.60	10.80	11.70	0.09	51.80		
10/30/95	1	3.12	464	4.5	13.60	1.08	0.92	14.60	47.50	15.10	0.32	67.90		
	7	12.3	168	3.0	0.02 <sup>U</sup>	0.04 <sup>U</sup>	0.004	0.07	0.02	0.01	0.03 <sup>U</sup>	2.36		
11/09/95	1	2.99	470	4.3	12.00	0.57	0.84	13.10	39.90	14.10	0.24	62.70		
	7	11.7	160	1.0	0.73	0.04 <sup>U</sup>	0.004	0.004	0.01 <sup>U</sup>	0.004	0.03 <sup>U</sup>	0.81 <sup>J</sup>		
11/15/95	1	2.72	459	5.4	12.90	0.63	0.86	13.60	44.10	14.70	0.27	65.20	452 <sup>J</sup>	40
	7	11.6	202	1.6	1.09	0.04	0.00	0.01	0.01	0.01	0.03	0.70	502 <sup>J</sup>	10
11/20/95	1	2.70	480	5.6	12.60	0.54	0.85	13.30	41.80	14.60	0.25	63.80		
	7	11.7	194	1.4	0.71	0.04	0.00	0.00	0.01	0.00	0.03	0.03		
11/29/95	1	3.16	523	5.3	12.40	0.41	0.86	13.30	40.50	15.00	0.26	64.90		
	7	11.6	349	2.3	0.02	0.04	0.00	0.22	0.01	0.00	0.03	0.13		
12/07/95	1	3.04	540	5.3	12.40	0.44	0.90	13.10 <sup>J</sup>	40.90	15.80	0.24 <sup>J</sup>	66.90		
	7	11.7	314	2.3	0.58	0.04 <sup>U</sup>	0.004	0.002	0.01 <sup>U</sup>	0.003	0.03 <sup>UJ</sup>	0.79 <sup>J</sup>		
12/13/95	1	2.97	534	5.0	11.80	0.26	0.90	12.60	37.40	15.60	0.23	65.00		
	7	8.31	325	2.0	8.25	0.04 <sup>U</sup>	0.85	10.50	14.10	15.10	0.11	61.00 <sup>J</sup>		

Table 7-1. Dissolved chemistry field data.

Dissolved Chemistry Field Data for the Crystal Mine Project														
Date	Pt	pH	E <sub>H</sub>	Temp	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	SO <sub>4</sub>	TSS
12/21/95	1	3.27	447	4.0	10.40	0.26	0.82	11.40	35.00	14.70	0.23	59.80	432	37
	7	3.78	382	1.4	9.89	0.05	0.70	10.10	16.20	12.50	0.13	51.00	436	29
12/28/95	1	3.09	427	4.8	10.40	0.19	0.85	11.50	34.50	15.10	0.24	60.90		
	7	4.37	319	1.4	4.33	0.04 <sup>U</sup>	0.49	5.69	7.19	8.85	0.05	34.20		
01/03/96	1	3.19	443	4.2	10.50	0.19	0.87	11.60	35.50	15.60	0.23	62.60		
	7	3.46	480	0.8	9.18	0.07	0.71	9.89	19.90	12.90	0.19	51.50		
01/08/96	1	3.11	418	4.9	9.52	0.15	0.78	10.40	31.60	14.10	0.19	56.50		
	7	10.9	173	2.0	0.18	0.04 <sup>U</sup>	0.004	0.25	0.01 <sup>U</sup>	0.02	0.03 <sup>U</sup>	0.10		
01/15/96	1	3.32	442	4.6	9.52	0.18	0.81	10.50	30.90	14.40	0.24	57.50		
	7	10.7	224	2.1	0.18	0.03 <sup>U</sup>	0.004	0.37	0.02	0.01	0.03 <sup>U</sup>	0.08		
01/22/96	1	3.13	445	4.0	9.51	0.10	0.81	10.30	29.80	15.00	0.19 <sup>J</sup>	59.60	402	29
	7	3.96	364	1.7	7.18	0.03 <sup>U</sup>	0.74	9.58	13.80	13.90	0.41	52.20	453	21
01/29/96	1	----	----	----	extreme cold - no samples									
	7	----	----	----										
02/06/96	1	2.54	505	4.3	9.25	0.11	0.83	9.96	32.50	15.30	0.19	60.50		
	7	11.5	182	1.7	1.22	0.03 <sup>U</sup>	0.004	0.003	0.02 <sup>U</sup>	0.004	0.03 <sup>U</sup>	0.55		
02/13/96	1	3.34	436	4.0	9.16	0.09	0.85	9.85	31.50	15.90	0.21	62.80		
	7	12.0	140	1.1	1.19	0.03 <sup>U</sup>	0.004	0.003	0.02 <sup>U</sup>	0.005	0.03 <sup>U</sup>	0.47		
02/22/96	1	3.44	425	----	7.90	0.06	0.76	8.56	26.40	14.10	0.15	54.90		
	7	11.1	257	----	0.02 <sup>U</sup>	0.03 <sup>U</sup>	0.004	0.003	0.02	0.03	0.03 <sup>U</sup>	0.06		
02/29/96	1	----	----	----	extreme cold - no samples									
	7	----	----	----										
03/05/96	1	3.20	429	3.8 <sup>J</sup>	8.45	0.09	0.83	9.05	28.90	15.20	0.18	58.40	407	33
	7	9.28	156	0.6 <sup>J</sup>	0.14	0.03 <sup>U</sup>	0.02	0.003	0.02 <sup>U</sup>	1.04	0.03 <sup>U</sup>	0.02	399	8
03/14/96	1	----	----	----	portal collapse - no water flowing through system - no									
	7	----	----	----										
03/18/96	1	3.21	429	4.1 <sup>J</sup>	7.90	0.06	0.76	8.39	26.40	14.40	0.19	55.80		
	7	7.35	219	0.5 <sup>J</sup>	0.03	0.03 <sup>U</sup>	0.46	0.03	0.03	10.70	0.03 <sup>U</sup>	22.50		
03/28/96	1	3.12	----	3.8 <sup>J</sup>	7.49	0.04	0.78	8.27	26.60	14.30	0.19	54.50		
	7	11.2	----	1.0 <sup>J</sup>	0.15	0.03 <sup>U</sup>	0.004	0.003	0.02 <sup>U</sup>	0.004	0.03 <sup>U</sup>	0.01 <sup>U</sup>		



Table 7-1. Dissolved chemistry field data.

[illegible]

Table 7-2. Sample results relative to the boundary conditions.

Constituent Sampled	Boundary Condition (ppm)	% Samples Below Boundary Condition
Aluminum	2.0	64
Arsenic	1.0	85
Cadmium	0.1	45
Copper	0.3	52
Iron	1.0	57
Manganese	1.0	42
Lead	0.6	99
Zinc	1.5	44
Sulfate	500	60
TSS	30	75

Table 7-3. Operating cost.

Parameter	Annual Cost	Cost per 1,000 Gallons Treated **
Reagent	\$2,300	\$0.14
Maintenance	\$7,500	\$0.44
Monitoring *	\$22,500	\$1.32
Sludge Removal and Disposal	\$65,000	\$3.82
Regulatory Reporting and Documentation	\$4,800	\$0.28
Capital Amortization	\$11,000	\$0.65
<b>Totals</b>	<b>\$78,300</b>	<b>\$6.65</b>
* assume bimonthly sessions		
** 17,000,000 gallons per year		

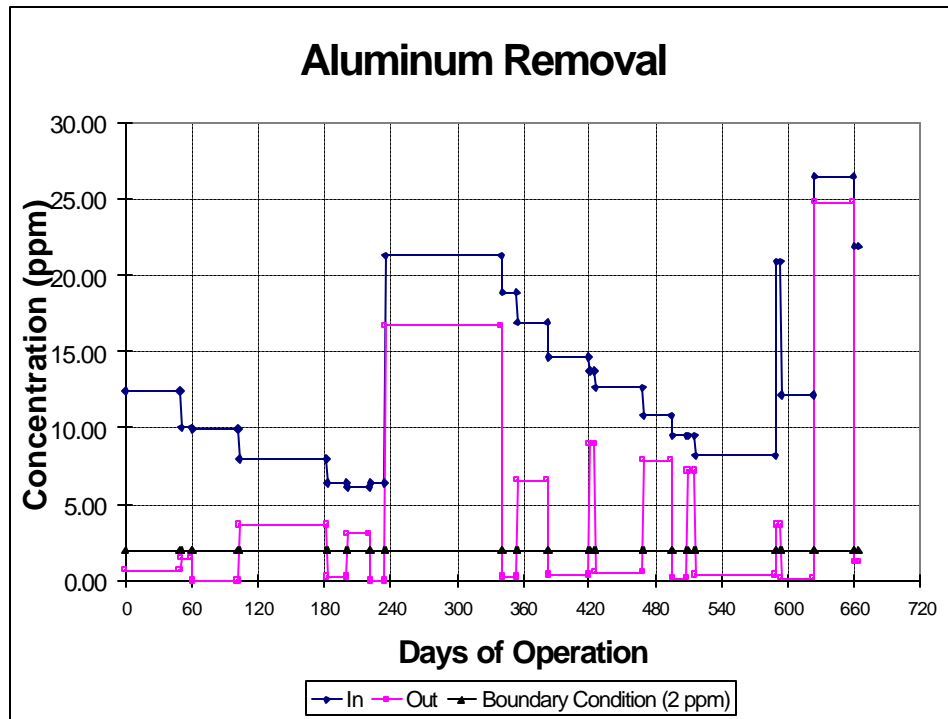


Figure 7-1. Aluminum removal.

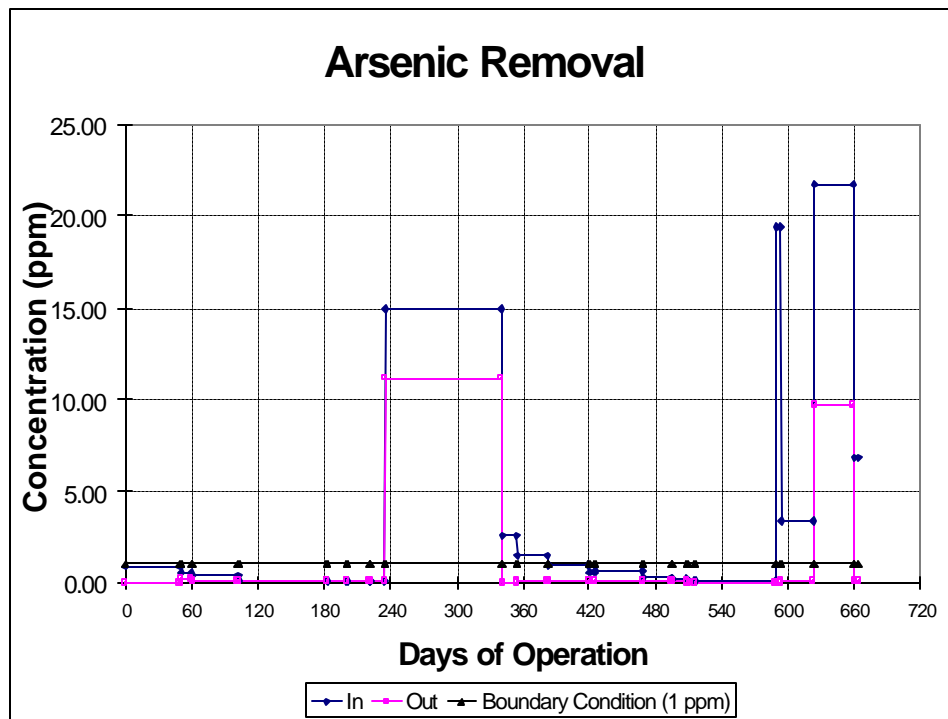


Figure 7-2. Arsenic removal.

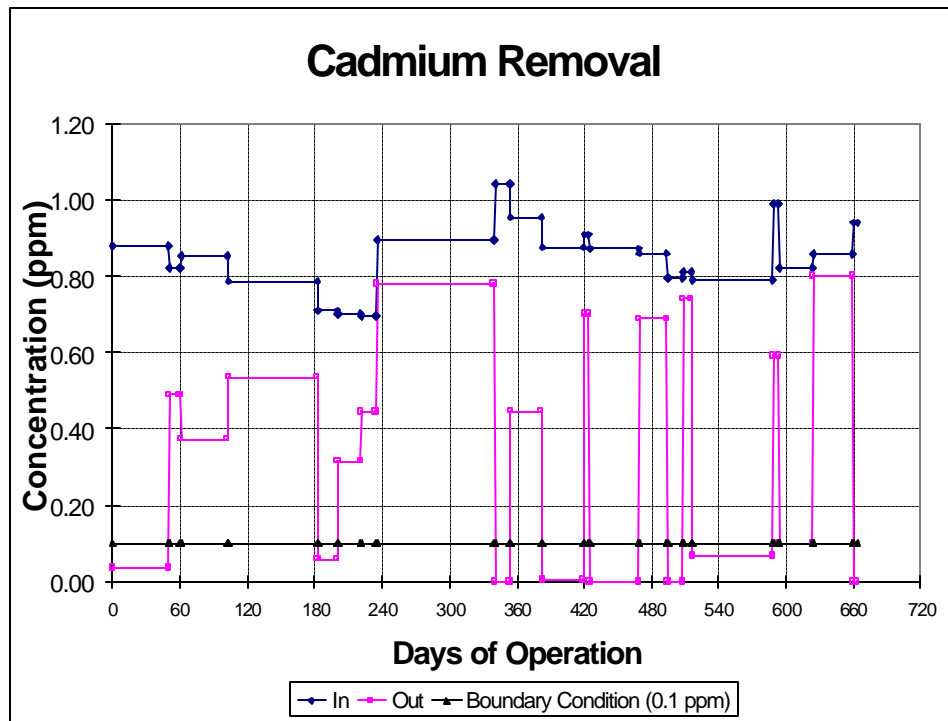


Figure 7-3. Cadmium removal.

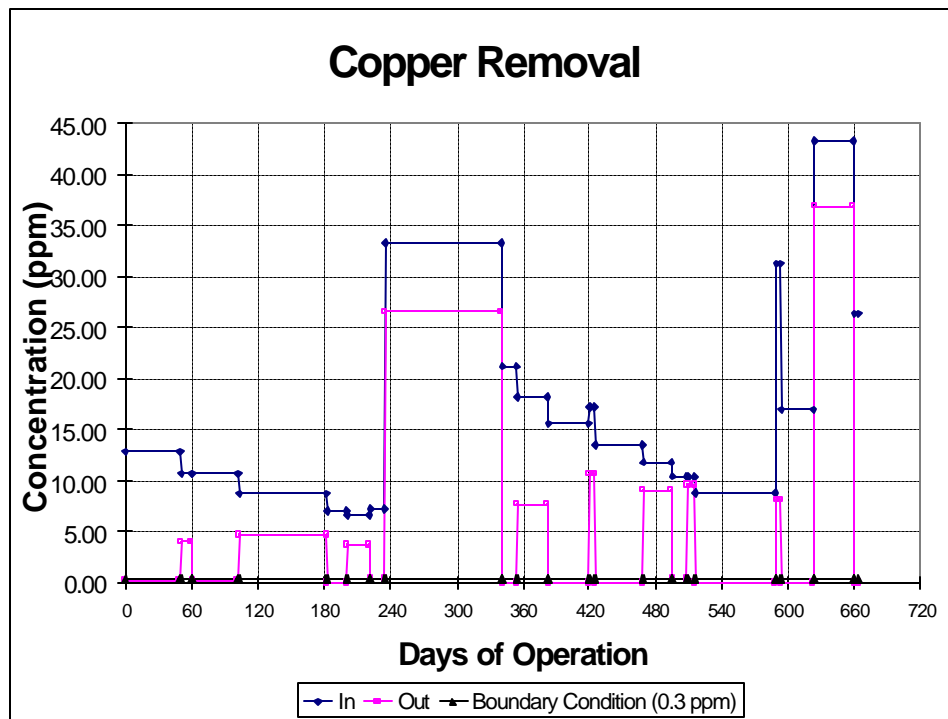


Figure 7-4. Copper removal.

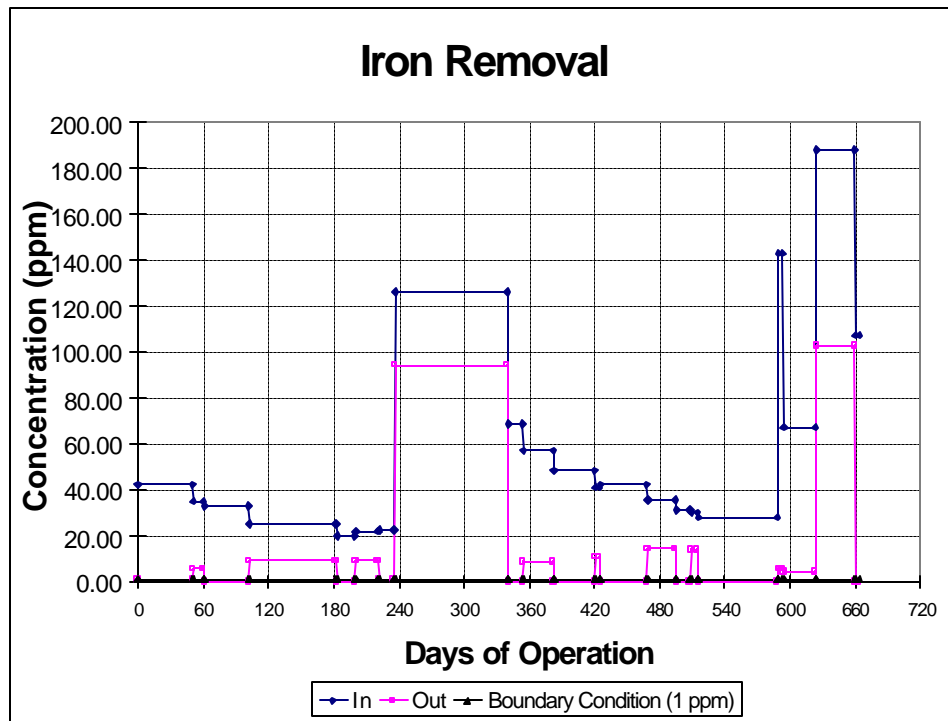


Figure 7-5. Iron removal.

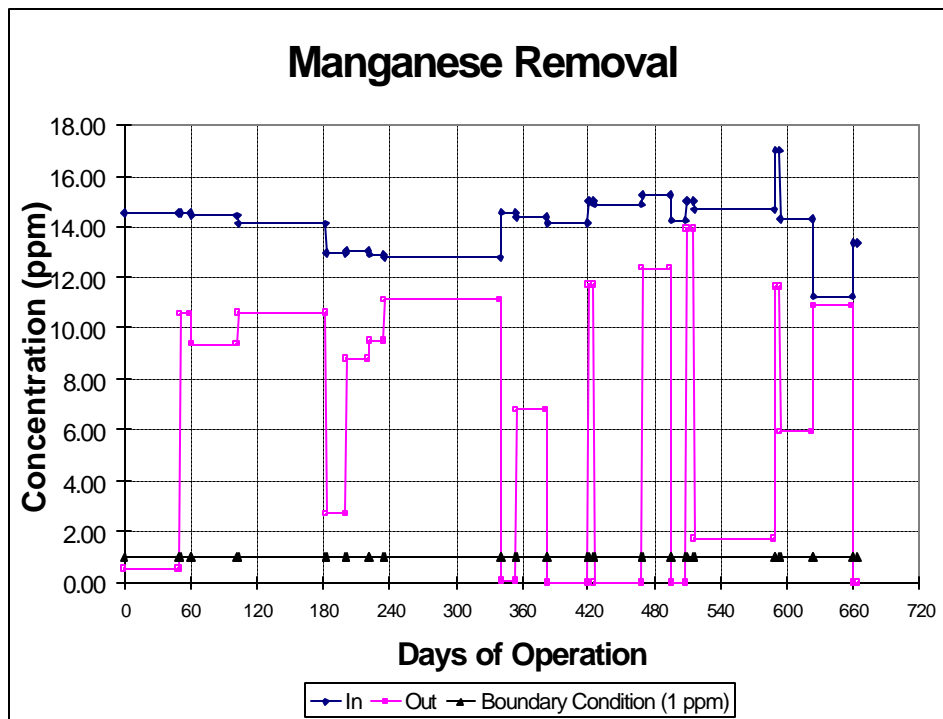


Figure 7-6. Manganese removal.

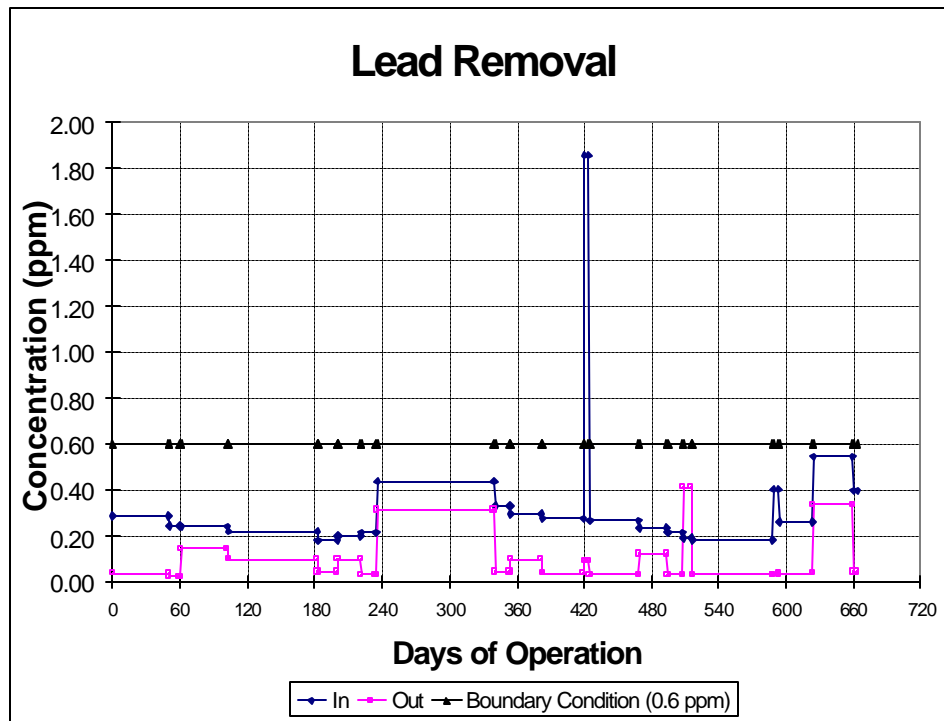


Figure 7-7. Lead removal.

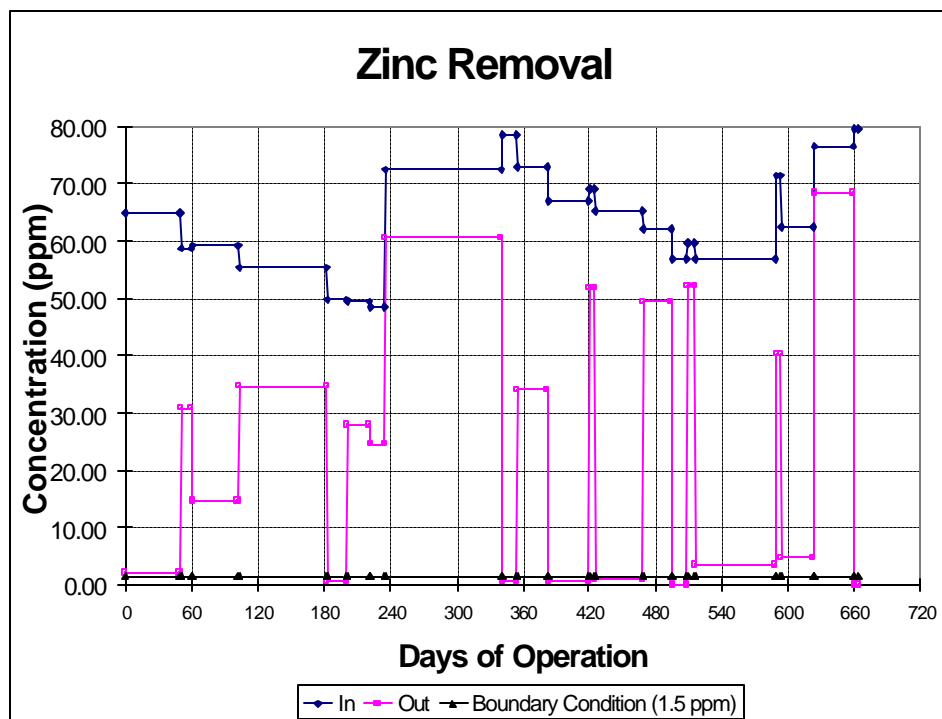


Figure 7-8. Zinc removal.

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## 8. Recommendations and Conclusions

The technology treatment train based on the AQUA-FIX device was a feasible method of removing heavy metals from acidic drainage; however, the system has numerous limitations that must be accounted for. The system can be thought of as a usable alternative while a more efficient, permanent, source control-type of remediation is being developed.

The system should not be used without the assistance of trained operators visiting the site at least once every 2 weeks. Personnel sent to the site must be familiar with its operation and be willing to make required adjustments to that

operation. Personnel simply sent to monitor the outfall of the system are not serving this purpose. Most changes that are minor in nature should be made to the original system to ensure a smoother operation of the system as a whole. These include the previously discussed longer auger and the wind screen.

With the use of trained operational personnel, the system as modified would serve the purpose of protecting surface waters from the effects of acidic, metal-laden drainage until the source of the drainage could be controlled.

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## 9. References

1. Environmental Protection Agency, *Contract Laboratory Program National Functional Guidelines for Inorganics Data Review*, 1994.